Water Quality and Quantity Inputs for the Urban Creeks Future Needs Assessment

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TABLE OF CONTENTS

INTRODUCTION

To develop estimates of pollutant loads for urban creeks in the Austin area it is necessary to determine the quantity and quality of stormwater runoff which might be expected from all sites within the watersheds of these creeks. The City of Austin has undertaken the most comprehensive water quality monitoring program in the United States. Almost 20 years of stormwater data collected by the City in this program form the basis for this study.

The annual pollutant loads derived from stormwater runoff from an area are commonly calculated using the formula suggested by the EPA (1992):

$$L_i = \left[\frac{(P)(CF)(Rv_i)}{12} \right] (C_i)(A_i)(2.72)$$

where:

L_i = Annual pollutant load (lb/ac/yr)

P = Annual precipitation (in/yr)

CF = Correction factor that adjusts for storms without runoff

Rv_I = Weighted average runoff coefficient

C_i = Average event mean concentration of the pollutant

A_i = Catchment area (acres)

The equation is normally applied to gauged watersheds where stormwater runoff quantity and quality has been measured during selected events and an estimate of average annual load is required. The concept can be extended to estimate loads from ungauged watersheds when estimates can be made of the values of the variables for all areas in the contributing watershed. For many of the variables, such as area and average rainfall this is a trivial task; however, estimating runoff coefficients and water quality for all areas is more daunting.

The City of Austin's stormwater monitoring program was designed to characterize the quantity and quality of runoff associated with various land uses such as single family residential, commercial, industrial, etc. Consequently, it was felt that a correlation between land use and stormwater runoff characteristics could be used to predict current pollutant loads in ungauged watersheds as well as future loads city-wide based on various development scenarios. This report presents the results of the analysis of this single land use monitoring data. This analysis is intended to develop estimates of runoff coefficients and average stormwater constituent concentrations for the Austin area.

SCOPE

The time and funds available for this study limit the detail with which the available data can be analyzed. Consequently, certain assumptions have been made about the reliability and accuracy of the data collection and processing. In particular, it has been assumed that each of the field sites was equipped to accurately measure flow and to collect samples representative of the runoff, and that samples were handled and analyzed in accordance with generally accepted protocols. The raw data was not examined for errors in transcription, laboratory reporting or for the methodology used to deal with censored data (i.e., values reported as below detection limit).

For each storm sampled, an event mean concentration (EMC) has been calculated by City staff as a flow weighted concentration based on the relative volumes associated with each discrete sample. It is assumed that these calculations were done correctly. The area and impervious cover of each of the monitored watersheds is assumed to accurately characterize the drainage area. The data used in this analysis consists of the runoff coefficients and EMCs for individual events for each of the monitored watersheds. Because of these limitations, the values developed during this initial review should not be considered final, but they are appropriate for planning purposes and model development.

RUNOFF COEFFICIENTS

To accurately characterize the impact of increases in impervious cover on the water quantity in urban creeks it is necessary to determine the amount of flow contributed by all portions of the watershed. This flow is derived from direct surface runoff during storm events as well as baseflow which originates from rainfall infiltrating on pervious areas of the watershed. Data from the single land use monitoring program will be used to develop estimates of the amount of surface runoff; however, none of these sites has dry weather flow. Therefore, the relationship between baseflow and land use will be derived from USGS data for large watersheds.

The runoff coefficient for a watershed is a statistical measure which attempts to express the relationship between rainfall and direct runoff as a constant value. It is well known that the runoff coefficient is not a constant, but depends on factors such as the antecedent soil moisture, rainfall intensity, and rainfall volume. In addition, extrapolation of rainfall depth measured at a single point to uniform coverage of the entire watershed also introduces errors into the estimate. For watersheds with a high degree of impervious cover, this extrapolation may result in an apparent contradiction for some storms as runoff depth exceeds the rainfall depth. Despite these shortcomings, the concept of a single runoff coefficient value for a watershed has found widespread acceptance among engineers for estimating stormwater volumes. Consequently, in this study, only a single value will be developed for a given area.

The term "runoff coefficient" also is commonly applied to one of the terms in the rational equation. In this usage, it is a coefficient which relates runoff rate to rainfall intensity. Although the values for the different applications are similar, the values are not interchangeable and should not be confused.

Although a runoff coefficient can be calculated for individual storms, it can also be defined to be the ratio of runoff to rainfall over a given time period. Since one of the goals of this research is to predict annual pollutant loads, an estimate of annual stormwater runoff is required. The long term average runoff is required for this calculation; therefore, the runoff coefficient for a site will be defined as suggested by Chow et al. (1988):

$$R_v = \frac{r_d}{\sum_{m=1}^{M} R_m}$$

where:

R_v = the watershed runoff coefficient

$\sum_{m=1}^{M} R_m$ = the total rainfall for all monitored events

r_d = the corresponding depth of runoff

There are other methods for calculating the average runoff coefficient for a site based on the underlying distribution of the data, area climate factors, or size of monitored events. These methods are much more complex and not routinely used by engineers for design purposes. In addition, because of the scatter in the data collected at each of the sites, the other methods do not significantly increase the accuracy of the estimate. Further refinement of the estimate of are runoff coefficients should include examination of the field sites to verify that each has been equipped to accurately measure flow and rainfall.

Single Land Use Runoff Data

Rainfall/runoff data is available for 18 watersheds in the Austin area, which have an impervious cover which ranges from near zero to approximately 100%. A list of the watersheds used in this analysis and their characteristics are shown in Table 1.

The runoff coefficient for an ungauged watershed is normally estimated by developing a relationship between impervious cover and runoff coefficient for other area watersheds. A perfect correlation between these two variables does not exist because of other factors which vary between the monitored watersheds such as slope, soil type, geology and other factors. Fortunately, these other factors are of secondary importance and most previous researchers have successfully predicted runoff coefficients based on impervious cover alone. A linear relationship was suggested by Shelley and Gaboury (1986), while Urbonas et al. (1990) fit their data with a 3^{rd} order polynomial.

The use of a linear relationship is attractive because of the well developed statistical foundation for estimating parameter uncertainty. However, one might expect that the effect of an increase in impervious cover of a watershed would depend on the amount of existing impervious cover. In the extreme case, it is unlikely that all of the first 5% of impervious cover in a watershed would be directly connected to the receiving water so its effect would be diminished by flowing across surrounding pervious areas.

Conversely, the last 5% of impervious cover would all be directly connected to the drainage system and receiving water. In addition, the best fit linear relationship predicts a negative runoff coefficient for areas with low impervious cover. Consequently, the rainfall/runoff data for Austin area watersheds were fit with a 2nd order polynomial as shown in Figure 1.

Table 1 Watersheds Used to Estimate Rainfall/Runoff Relationship

Watershed	Impervious Cover	Area (ac)	Number of Observations	Total Rain (in)	Runoff Coefficient
Alta Vista	0.62	0.7	18	14.3	0.42
Brodie Oaks	0.95	30.9	10	14.0	0.91
Hwy 6 BMP	0.58	4.9	57	37.5	0.36
Barton Ridge Plaza	0.80	3.0	37	22.9	0.77
Hwy 5 BMP	0.64	4.6	38	26.3	0.68
Holly @ Anthony	0.43	51.3	23	15.9	0.36
Airport	0.46	99.1	15	13.5	0.38
Bear @ 1826	0.01	3563	29	31.2	0.04
Windago Way	0.01	50	78	48.9	0.03
Jollyville Rd.	0.94	7.0	29	23.6	0.77
Lost Creek	0.22	210	25	27.3	0.14
Metric Blvd.	0.6	203	45	28.0	0.48
Spy Glass	0.88	3	29	21.1	0.67
Barton Creek Mall	0.86	47	52	55.6	0.80
St. Elmo East	0.60	16.4	21	15.9	0.60
St. Elmo West	0.84	5.8	21	15.9	0.72
Tar Branch	0.45	49	18	15.0	0.26
Travis Country	0.42	42	43	40.0	0.19

Since soil type and geology affect the value of the runoff coefficient, one would expect to see consistent differences in Austin area values related to these factors. Potentially, one of the more important regional differences in this area is related to the presence of the recharge zone of the Edwards aquifer. This is the area underlain by porous Edwards limestone and which might be expected to exhibit a lower runoff coefficient than those areas underlain by clays and relatively impermeable limestone. The runoff coefficients for sites located on the recharge zone have been plotted in Figure

1 using square symbols. As many of these sites fall above the best fit regression line as below indicating that the line applies equally well to areas on and off the recharge zone.

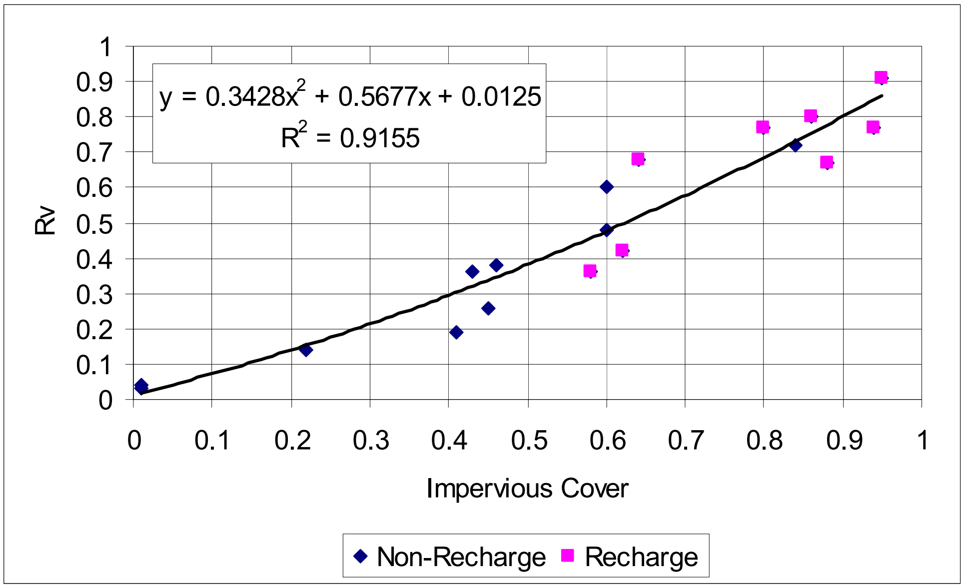

Figure 1 Relationship Between Runoff Coefficient and Impervious Cover

Large Watershed Baseflow Data

The effect of increased impervious cover on the amount of baseflow in the Austin area creeks was estimated with stream flow data collected by the USGS. The observed hydrograph was divided into baseflow and direct runoff components with a computer program developed City of Austin staff. The separation of these two components is by nature an arbitrary process, and many different algorithms are commonly used. Consequently, there is no unique “correct” solution. The City program was not analyzed for methodology; however, the output of the flow separation program was reviewed for several monitoring stations and the results appear to be reasonable.

The amount of baseflow (as a fraction of the rainfall) was calculated for several creeks with different levels of impervious cover. A subsurface runoff coefficient, R_s, can be defined in a manner analogous to the conventional surface runoff coefficient as the total baseflow divided by the total rainfall for the corresponding period. A list of the sites and amount of impervious cover is contained in Table 1. The amount of impervious cover for each watershed was estimated from maps of land use provided by the City

Planning Department. The department also provided a table which related land use to the degree of impervious cover.

Table 2 USGS Sites Used to Estimate Baseflow

Site	Impervious Cover	R_s
Barton Creek @ Lost Creek	0.09	0.14
Williamson Creek @ Oak Hill	0.16	0.12
Shoal Creek @ 12^{th}	0.54	0.03
Walnut Creek @ Webberville	0.30	0.09
Bear Creek @ 1826	0.07	0.16
Slaughter Creek @ 1826	0.13	0.18
Bull Creek @ Loop 360	0.14	0.15
Boggy	0.53	0.02

To determine the effect of impervious cover on the amount of baseflow, a linear regression was performed on the two variables as shown in Figure 2. A perfect correlation would not be expected because of differences in soil type, bedrock geology and other factors that influence the amount of rainfall which reappears in a given stream. The regression line intercepts the x-axis at an impervious cover of 0.87, indicating that no baseflow would be generated from land uses with greater impervious cover.

WATER QUALITY

The total constituent load delivered by each creek is a function of the quality and quantity of both baseflow and direct storm runoff. Consequently, it is necessary to estimate the average water quality for both flow regimes and to relate that quality to the land use, impervious cover or other characteristics of the watershed. The water quality of stormwater discharges can be estimated from the single land use monitoring data collected by the City; however, since there is no baseflow at these sites, the relationship between baseflow quality and watershed characteristics must be estimated from the large watershed data collected by the USGS.

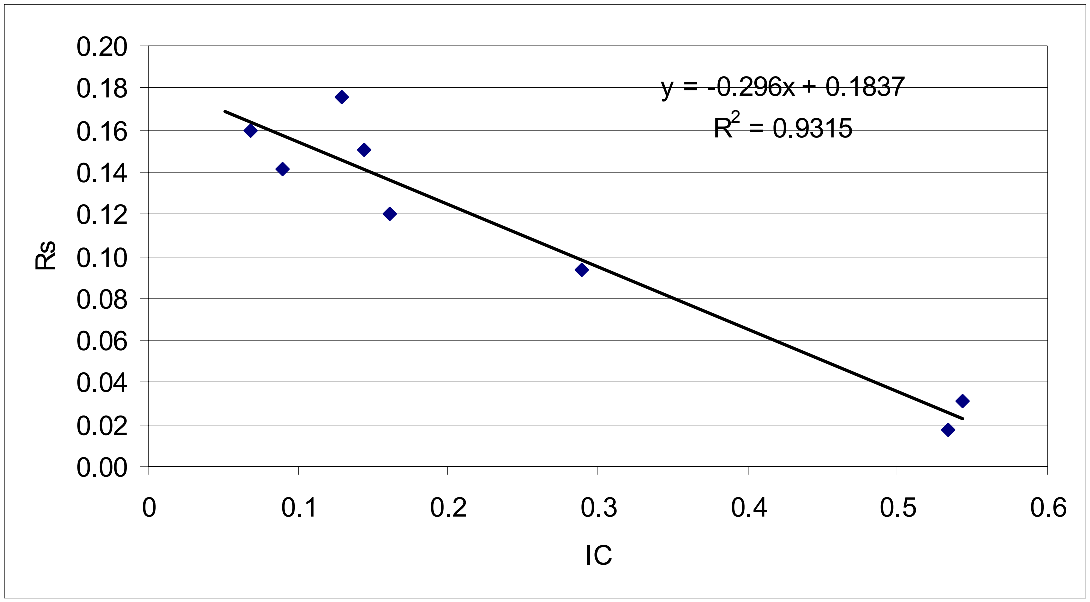

Figure 2 Relationship Between Impervious Cover and Baseflow

Single Land Use Water Quality Data

It is normally assumed that the quality of stormwater runoff from an area is largely a function of the land use. Consequently, most stormwater monitoring programs (including those mandated by the EPA) are developed to assess the quality associated with specific land uses. If a municipality were to develop a program based on sampling from watersheds which each have a unique land use, it is likely that each land use would have a unique value associated with it. In all subsequent calculations it would be assumed that all other areas with the same land use would have a similar average water quality. The City of Austin monitoring program was large enough to support the monitoring of several sites with similar land uses. In particular, there are multiple sites representing single and multi-family residential, commercial, industrial and other land uses. There are then two main objectives. The first is to characterize the "average" quality of stormwater runoff for the monitored site (i.e., that value when multiplied by the annual runoff produces the total annual load from the watershed). The second is to extrapolate those data to develop "average" water quality values for ungauged watersheds based on land use or other considerations.

Event mean concentrations have been developed by City staff for individual storms at the monitoring sites based on a flow weighted average concentration of discrete samples. There are several possible methodologies which use these values to calculate the concentration which represents the long term average quality. The choice of methodology might depend on assumptions about the underlying distribution of the data, the types of storms sampled relative to those that occur most commonly in the area, or other factors. It is also helpful to select a methodology which is widely accepted by the engineering and scientific communities. Consequently, the method recommended by the Driscoll (1983) and Gilbert (1987) for calculation of average concentrations for constituents which exhibit a lognormal distribution will be used. This method calculates the average concentration of a constituent at a site as:

$$M = e^{(u+\frac{w^2}{2})}$$

where:
M = average concentration
u = mean of the log transformed EMCs
w^2 = variance of the log transformed EMCs

Once the average concentration for a site has been determined, it is necessary to estimate concentrations for other, ungauged watersheds. It is commonly assumed that the type of land use is the major factor controlling the quality of stormwater runoff; however, these data did not strongly support that assumption. Within each land use category, it was found that concentrations varied widely for all constituents, so that the average concentration for each land use was not statistically different from those calculated for other land uses with multiple sites. This was also the conclusion of the EPA based on the analysis of water quality from sites across the country as part of the National Urban Runoff Program (1983). However, a fairly strong linear correlation with impervious cover was evident for many constituents and these relationships were used to estimate the water quality derived from ungauged watersheds. Concentrations of constituents correlated with impervious cover at a confidence level of less than 85% were estimated based on the arithmetic mean of all monitored sites.

There were several sites which were part of the monitoring program were excluded from this analysis. The list of sites and the reason for not using the data are listed in Table 3.

Table 3 Monitoring Sites Excluded from Analysis

Site	Comments
Airport	Water quality not representative of most urban land uses
Alta Vista	Samples collected after runoff flows across grassy swale
Old Bear Creek	Monitoring data challenged in court
Travis Country Ditch	Concentrations much lower than adjacent site, represents water quality after grassy swale
Holly @ Anthony	Concentrations far higher than at any other site for all constituents. May include in future analyses pending field check for illegal connections or dumping.

BOD Concentration

Table 4 Sites Used to Estimate BOD Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ck. Sq. Mall	COMM	47.0	0.86	22	13
Barton Ridge Inflow	COMM	3.0	0.80	14	13
Lavaca	COMM	13.7	0.97	21	19
5th Street	COMM	4.0	0.95	18	22
St. Elmo East	INDU	16.4	0.60	6	7
East 7th Street	INDU	29.3	0.70	2	14
Metric Blvd.	INDU	202.9	0.60	21	14
Highwood Apts.	MFR	3.0	0.50	24	9
Burton Road	MFR	12.0	0.82	17	20
Spy Glass	OFFI	1.5	0.86	13	14
Rollingwood	SFR	62.8	0.21	8	6
Lost Creek	SFR	209.9	0.23	18	7
Maple Run	SFR	27.8	0.36	24	8
Hart Lane	SFR	371.0	0.39	20	10
Travis Country Pipe	SFR	41.6	0.41	15	12
Jollyville Road	TRAN	9.5	0.81	24	8
Windago Way	UNDEV	50.0	0.01	8	4

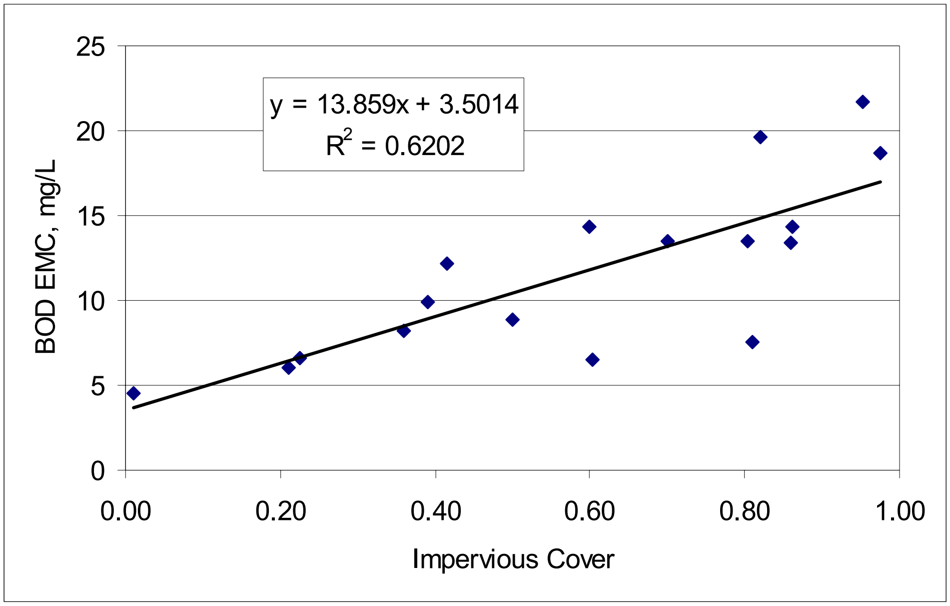

Figure 3 Relationship Between BOD and Impervious Cover

COD Concentrations

Table 5 Sites Used to Estimate COD Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ridge Inflow	COMM	3.0	0.80	15	80
Barton Ck. Sq. Mall	COMM	47.0	0.86	23	106
Lavaca	COMM	13.7	0.97	22	115
5th Street	COMM	4.0	0.95	25	154
St. Elmo East	INDU	16.4	0.60	6	51
Metric Blvd.	INDU	202.9	0.60	21	78
East 7th Street	INDU	29.3	0.70	3	124
Highwood Apts.	MFR	3.0	0.50	25	39
Burton Road	MFR	12.0	0.82	17	120
Spy Glass	OFFI	1.5	0.86	15	85
Maple Run	SFR	27.8	0.36	25	34
Hart Lane	SFR	371.0	0.39	29	44
Lost Creek	SFR	209.9	0.23	19	49
Rollingwood	SFR	62.8	0.21	20	51
Travis Country Pipe	SFR	41.6	0.41	19	71
HWY BMP 5 Inflow	TRAN	4.6	0.64	5	63
Jollyville Road	TRAN	9.5	0.81	28	76
Windago Way	UNDEV	50.0	0.01	8	39

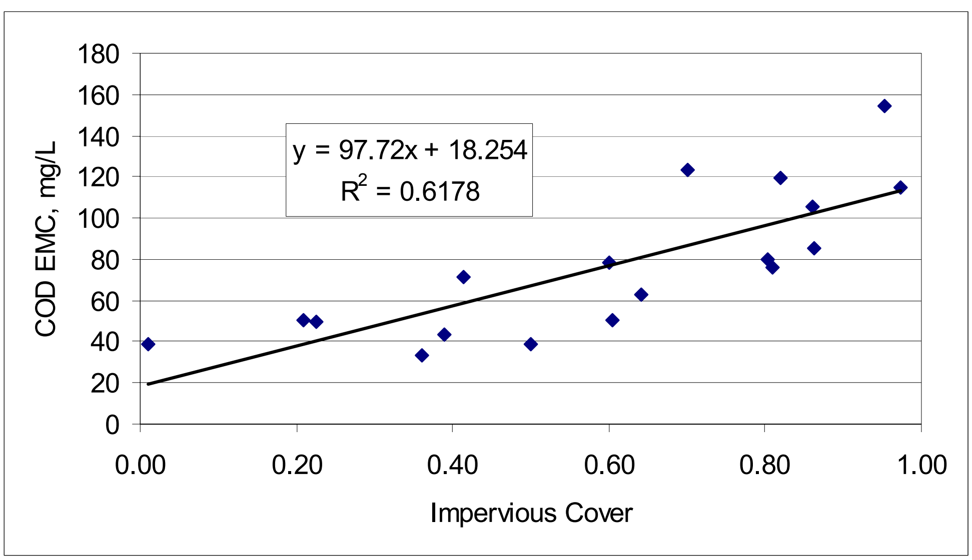

Figure 4 Relationship Between COD and Impervious Cover

Copper Concentrations

Table 6 Sites Used to Estimate Copper Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ridge Inflow	COMM	3.0	0.80	5	0.007
5th Street	COMM	4.0	0.95	9	0.025
Lavaca	COMM	13.7	0.97	12	0.029
St. Elmo East	INDU	16.4	0.60	7	0.014
East 7th Street	INDU	29.3	0.70	2	0.016
Metric Blvd.	INDU	202.9	0.60	9	0.030
Highwood Apts.	MFR	3.0	0.50	25	0.009
Burton Road	MFR	12.0	0.82	11	0.022
Spy Glass	OFFI	1.5	0.86	4	0.011
Travis Country Pipe	SFR	41.6	0.41	11	0.007
Maple Run	SFR	27.8	0.36	25	0.007
Rollingwood	SFR	62.8	0.21	10	0.009
Lost Creek	SFR	209.9	0.23	11	0.013
Hart Lane	SFR	371.0	0.39	18	0.015
Jollyville Road	TRAN	9.5	0.81	28	0.018
Windago Way	UNDEV	50.0	0.01	3	0.008

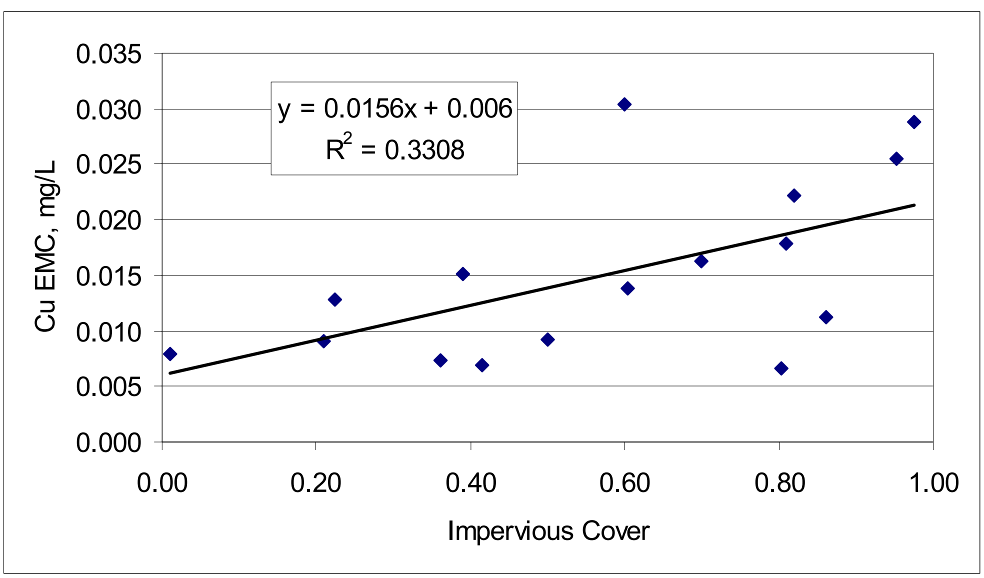

Figure 5 Relationship Between Copper and Impervious Cover

Dissolved Phosphorus Concentrations

Table 7 Sites Used to Estimate Dissolved Phosphorus Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ridge Inflow	COMM	3.0	0.80	12	0.138
5th Street	COMM	4.0	0.95	18	0.252
Lavaca	COMM	13.7	0.97	11	0.427
St. Elmo East	INDU	16.4	0.60	7	0.079
Metric Blvd.	INDU	202.9	0.60	17	0.168
East 7th Street	INDU	29.3	0.70	2	0.207
Burton Road	MFR	12.0	0.82	8	0.318
Spy Glass	OFFI	1.5	0.86	13	0.138
Lost Creek	SFR	209.9	0.23	7	0.130
Travis Country Pipe	SFR	41.6	0.41	13	0.196
Windago Way	UNDEV	50.0	0.01	5	0.044

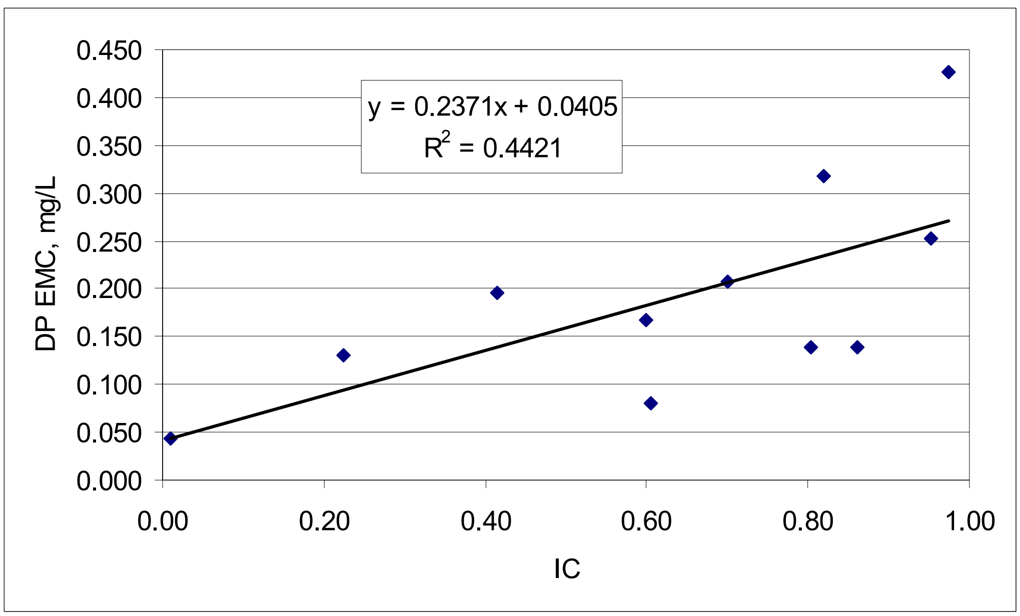

Figure 6 Relationship Between Dissolved Phosphorus and Impervious Cover

Ammonia Concentration

Table 8 Sites Used to Estimate Ammonia Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ridge Inflow	COMM	3.0	0.80	15	0.299
Lavaca	COMM	13.7	0.97	13	0.367
5th Street	COMM	4.0	0.95	25	0.379
St. Elmo East	INDU	16.4	0.60	7	0.299
Metric Blvd.	INDU	202.9	0.60	16	0.302
East 7th Street	INDU	29.3	0.70	3	0.319
Highwood Apts.	MFR	3.0	0.50	25	0.223
Burton Road	MFR	12.0	0.82	8	0.300
Spy Glass	OFFI	1.5	0.86	15	0.222
Rollingwood	SFR	62.8	0.21	12	0.179
Maple Run	SFR	27.8	0.36	25	0.205
Lost Creek	SFR	209.9	0.23	11	0.207
Hart Lane	SFR	371.0	0.39	20	0.214
Travis Country Pipe	SFR	41.6	0.41	16	0.306
Jollyville Road	TRAN	9.5	0.81	28	0.400
Windago Way	UNDEV	50.0	0.01	7	0.074

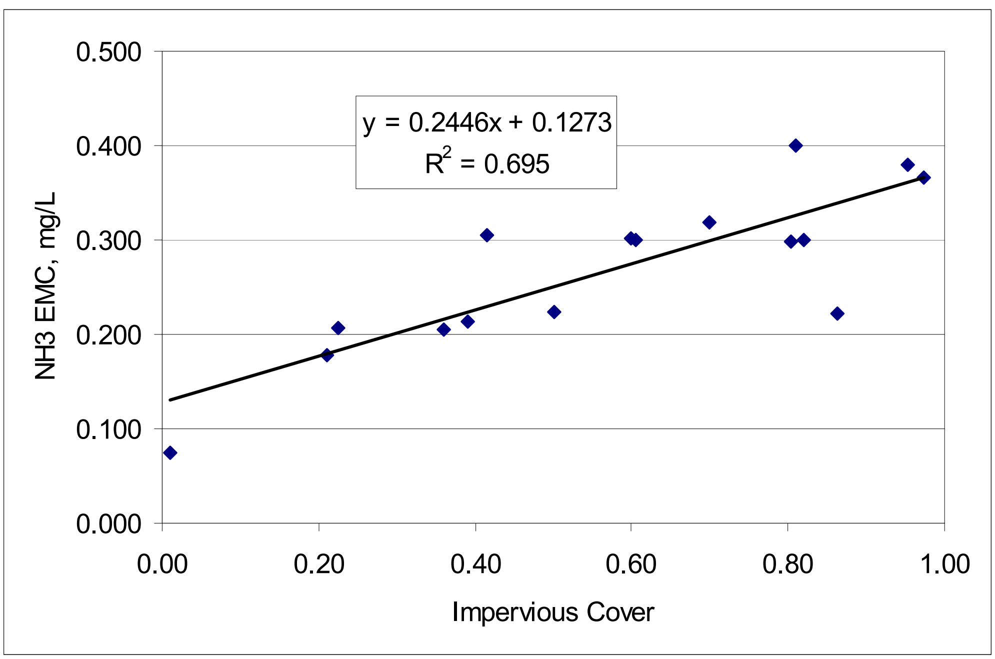

Figure 7 Relationship Between Ammonia and Impervious Cover

Nitrate Concentrations

Nitrate concentrations in stormwater runoff or not correlated with either land use or impervious cover, so the average concentration for all sites of 0.82 mg/L-N was used.

Table 9 Sites Used to Estimate Nitrate Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ck. Sq. Mall	COMM	47.0	0.86	23	0.422
Lavaca	COMM	13.7	0.97	21	0.676
Barton Ridge Inflow	COMM	3.0	0.80	15	0.690
5th Street	COMM	4.0	0.95	20	0.839
Metric Blvd.	INDU	202.9	0.60	20	0.692
St. Elmo East	INDU	16.4	0.60	6	1.490
East 7th Street	INDU	29.3	0.70	2	2.184
Highwood Apts.	MFR	3.0	0.50	25	0.293
Burton Road	MFR	12.0	0.82	15	0.713
Spy Glass	OFFI	1.5	0.86	16	0.889
Maple Run	SFR	27.8	0.36	25	0.427
Lost Creek	SFR	209.9	0.23	16	0.630
Travis Country Pipe	SFR	41.6	0.41	18	0.662
Rollingwood	SFR	62.8	0.21	20	0.919
Hart Lane	SFR	371.0	0.39	30	1.148
HWY BMP 5 Inflow	TRAN	4.6	0.64	2	0.430
Jollyville Road	TRAN	9.5	0.81	27	0.472
Windago Way	UNDEV	50.0	0.01	9	1.230

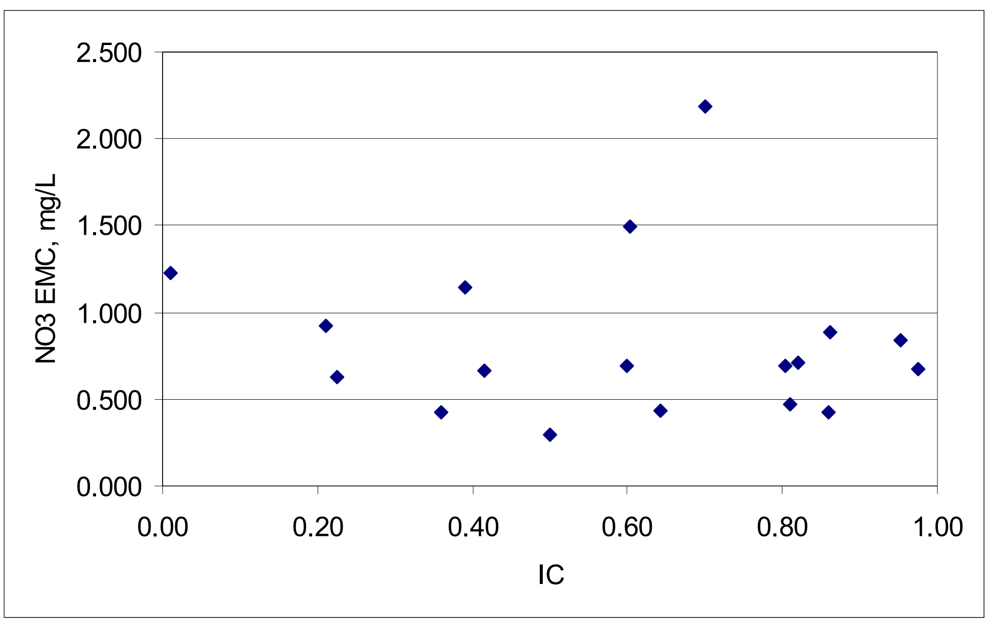

Figure 8 Relationship (or lack of) Between Nitrate and Impervious Cover

Lead Concentration

Table 10 Sites Used to Estimate Lead Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ridge Inflow	COMM	3.0	0.80	5	0.013
5th Street	COMM	4.0	0.95	9	0.036
Lavaca	COMM	13.7	0.97	10	0.075
St. Elmo East	INDU	16.4	0.60	6	0.010
East 7th Street	INDU	29.3	0.70	2	0.024
Metric Blvd.	INDU	202.9	0.60	9	0.031
Highwood Apts.	MFR	3.0	0.50	25	0.011
Burton Road	MFR	12.0	0.82	11	0.024
Spy Glass	OFFI	1.5	0.86	3	0.015
Maple Run	SFR	27.8	0.36	25	0.007
Lost Creek	SFR	209.9	0.23	11	0.007
Rollingwood	SFR	62.8	0.21	10	0.014
Travis Country Pipe	SFR	41.6	0.41	12	0.015
Hart Lane	SFR	371.0	0.39	18	0.044
HWY BMP 5 Inflow	TRAN	4.6	0.64	2	0.038
Jollyville Road	TRAN	9.5	0.81	28	0.049
Windago Way	UNDEV	50.0	0.01	3	0.007

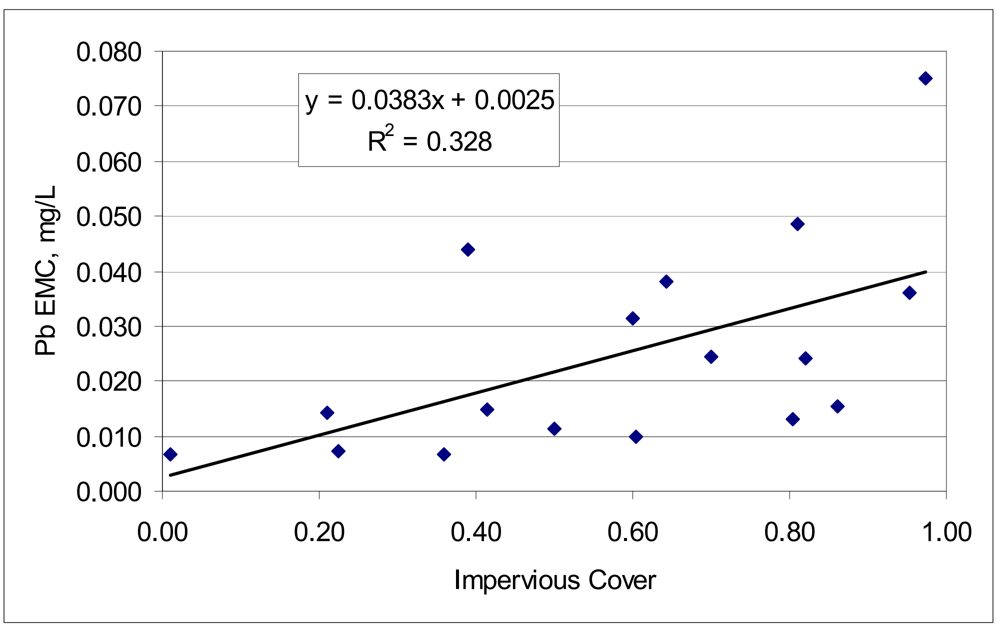

Figure 9 Relationship Between Lead and Impervious Cover

TKN Concentration

Table 11 Sites Used to Estimate TKN Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ck. Sq. Mall	COMM	47.0	0.86	23	1.77
Barton Ridge Inflow	COMM	3.0	0.80	15	1.85
Lavaca	COMM	13.7	0.97	22	2.50
5th Street	COMM	4.0	0.95	23	3
St. Elmo East	INDU	16.4	0.60	7	1.06
Metric Blvd.	INDU	202.9	0.60	21	1.83
East 7th Street	INDU	29.3	0.70	3	2.15
Highwood Apts.	MFR	3.0	0.50	22	0.69
Burton Road	MFR	12.0	0.82	18	2.01
Spy Glass	OFFI	1.5	0.86	15	1.58
Maple Run	SFR	27.8	0.36	25	0.84
Hart Lane	SFR	371.0	0.39	20	0.97
Rollingwood	SFR	62.8	0.21	12	1.03
Lost Creek	SFR	209.9	0.23	18	1.45
Travis Country Pipe	SFR	41.6	0.41	17	1.90
Jollyville Road	TRAN	9.5	0.81	27	1.09
HWY BMP 5 Inflow	TRAN	4.6	0.64	2	1.21
Windago Way	UNDEV	50.0	0.01	9	0.88

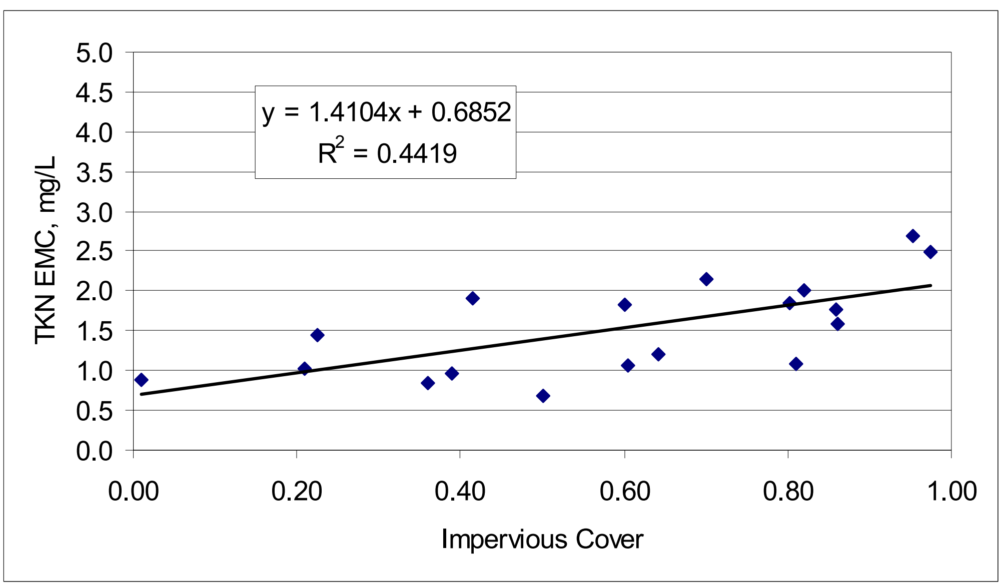

Figure 10 Relationship Between TKN and Impervious Cover

TOC Concentration

Table 12 Sites Used to Estimate TOC Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ridge Inflow	COMM	3.0	0.80	14	6
Lavaca	COMM	13.7	0.97	14	11
5th Street	COMM	4.0	0.95	21	21
Barton Ck. Sq. Mall	COMM	47.0	0.86	23	25
St. Elmo East	INDU	16.4	0.60	7	9
East 7th Street	INDU	29.3	0.70	3	9
Metric Blvd.	INDU	202.9	0.60	15	13
Highwood Apts.	MFR	3.0	0.50	25	10
Burton Road	MFR	12.0	0.82	7	14
Spy Glass	OFFI	1.5	0.86	13	18
Lost Creek	SFR	209.9	0.23	10	7
Travis Country Pipe	SFR	41.6	0.41	18	9
Hart Lane	SFR	371.0	0.39	32	10
Maple Run	SFR	27.8	0.36	25	12
Rollingwood	SFR	62.8	0.21	19	20
HWY BMP 5 Inflow	TRAN	4.6	0.64	5	7
Jollyville Road	TRAN	9.5	0.81	24	26
Windago Way	UNDEV	50.0	0.01	8	8

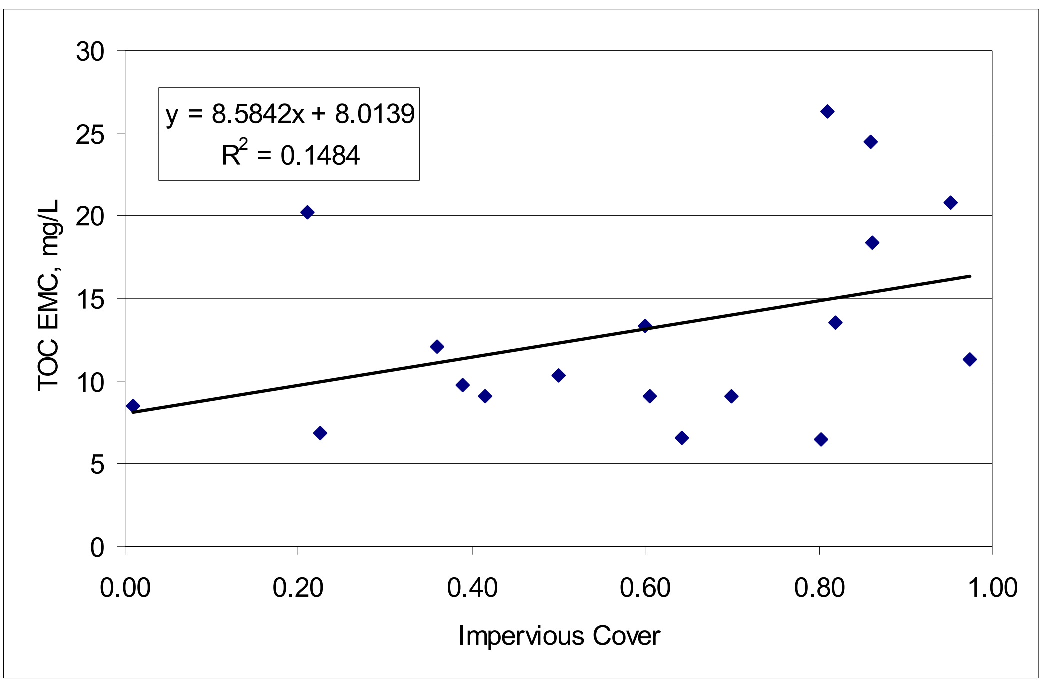

Figure 11 Relationship Between TOC and Impervious Cover

Total Phosphorous Concentration

Table 13 Sites Used to Estimate Total Phosphorous Concentration

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ck. Sq. Mall	COMM	47.0	0.86	23	0.249
Barton Ridge Inflow	COMM	3.0	0.80	15	0.391
Lavaca	COMM	13.7	0.97	22	0.552
5th Street	COMM	4.0	0.95	23	0.617
St. Elmo East	INDU	16.4	0.60	7	0.307
Metric Blvd.	INDU	202.9	0.60	22	0.470
East 7th Street	INDU	29.3	0.70	3	1.104
Highwood Apts.	MFR	3.0	0.50	24	0.211
Burton Road	MFR	12.0	0.82	17	0.592
Spy Glass	OFFI	1.5	0.86	15	0.216
Maple Run	SFR	27.8	0.36	25	0.249
Rollingwood	SFR	62.8	0.21	19	0.261
Hart Lane	SFR	371.0	0.39	33	0.295
Lost Creek	SFR	209.9	0.23	18	0.307
Travis Country Pipe	SFR	41.6	0.41	18	0.414
Jollyville Road	TRAN	9.5	0.81	28	0.222
HWY BMP 5 Inflow	TRAN	4.6	0.64	2	0.301
Windago Way	UNDEV	50.0	0.01	9	0.153

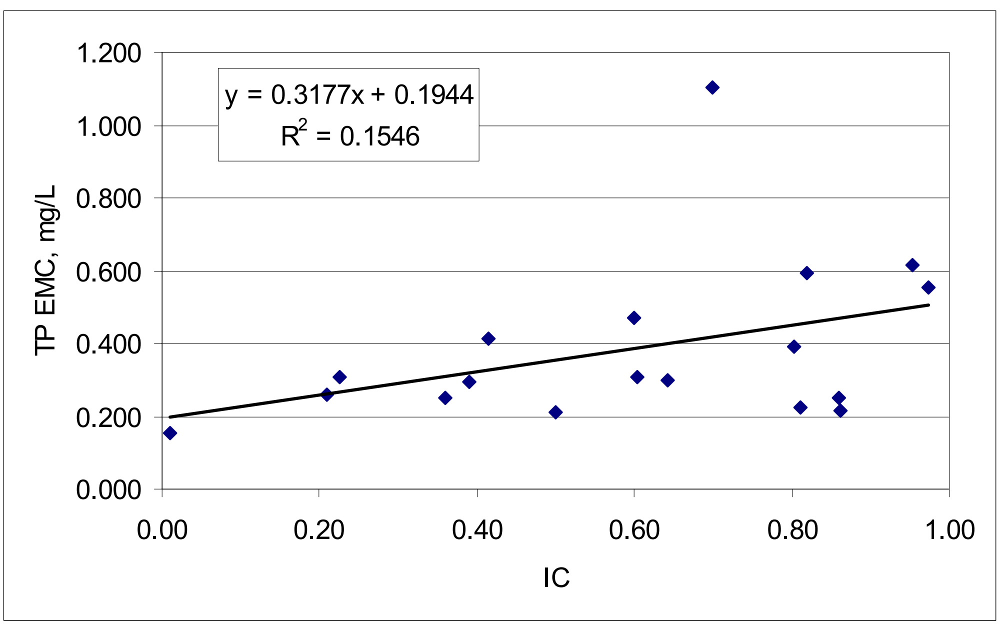

Figure 12 Relationship Between Total Phosphorus and Impervious Cover

TSS Concentration

A TSS concentration of 190 mg/L was used based on the average of all monitored sites.

Table 14 Sites Used to Estimate TSS Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
5th Street	COMM	4.0	0.95	18	142
Lavaca	COMM	13.7	0.97	23	179
Barton Ck. Sq. Mall	COMM	47.0	0.86	23	231
Barton Ridge Inflow	COMM	3.0	0.80	15	289
St. Elmo East	INDU	16.4	0.60	6	155
East 7th Street	INDU	29.3	0.70	3	193
Metric Blvd.	INDU	202.9	0.60	22	268
Highwood Apts.	MFR	3.0	0.50	25	116
Burton Road	MFR	12.0	0.82	17	296
Spy Glass	OFFI	1.5	0.86	13	66
Lost Creek	SFR	209.9	0.23	18	110
Travis Country Pipe	SFR	41.6	0.41	18	128
Hart Lane	SFR	371.0	0.39	33	156
Rollingwood	SFR	62.8	0.21	19	206
Maple Run	SFR	27.8	0.36	25	305
HWY BMP 5 Inflow	TRAN	4.6	0.64	5	128
Jollyville Road	TRAN	9.5	0.81	28	335
Windago Way	UNDEV	50.0	0.01	10	95

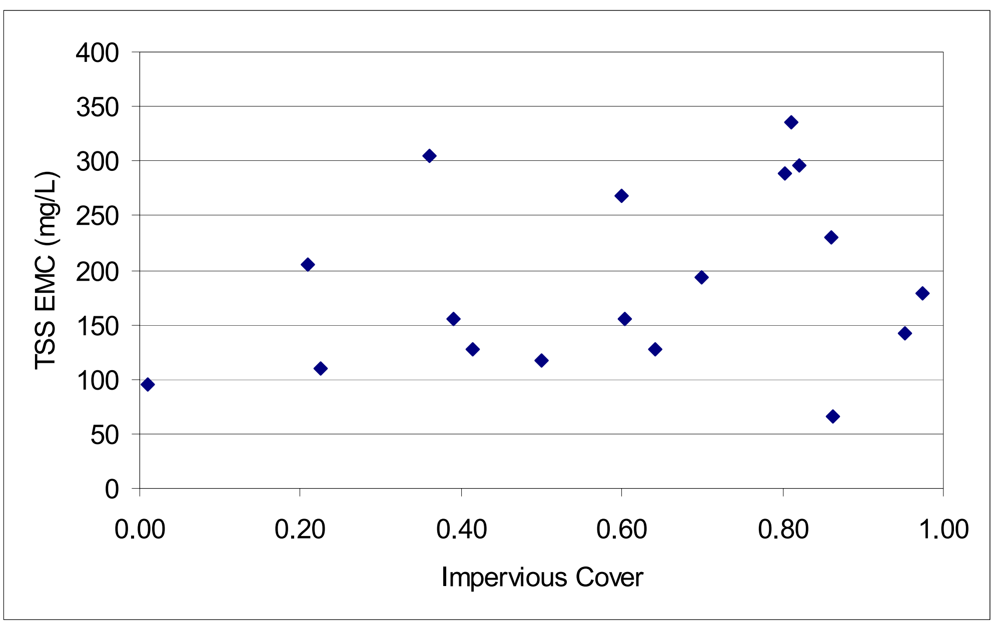

Figure 13 Relationship Between TSS and Impervious Cover

Zinc Concentrations

Table 15 Sites Used to Estimate Zinc Concentrations

Site	Land Use	Drainage	Imperv.	# EMCs	Average EMC (mg/L)
Barton Ridge Inflow	COMM	3.0	0.80	4	0.094
5th Street	COMM	4.0	0.95	10	0.234
Lavaca	COMM	13.7	0.97	9	0.271
St. Elmo East	INDU	16.4	0.60	6	0.098
East 7th Street	INDU	29.3	0.70	2	0.108
Metric Blvd.	INDU	202.9	0.60	9	0.174
Highwood Apts.	MFR	3.0	0.50	25	0.045
Burton Road	MFR	12.0	0.82	11	0.131
Spy Glass	OFFI	1.5	0.86	4	0.099
Maple Run	SFR	27.8	0.36	25	0.022
Rollingwood	SFR	62.8	0.21	10	0.039
Travis Country Pipe	SFR	41.6	0.41	10	0.045
Lost Creek	SFR	209.9	0.23	10	0.047
Hart Lane	SFR	371.0	0.39	18	0.051
HWY BMP 5 Inflow	TRAN	4.6	0.64	6	0.145
Jollyville Road	TRAN	9.5	0.81	28	0.170
Windago Way	UNDEV	50.0	0.01	3	0.065

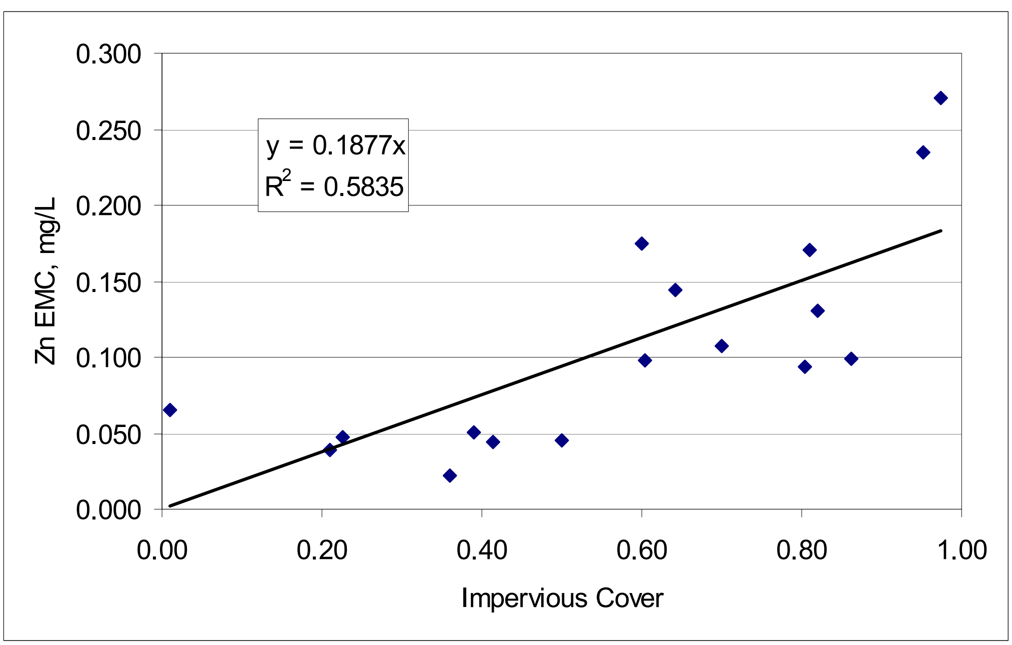

Figure 14 Relationship Between Zinc and Impervious Cover

Baseflow Water Quality Data

The relationship between the quality of baseflow and land use was determined from an analysis of the large watershed water quality data. The USGS sites on the large watersheds sample water derived from a wide range of land uses and impervious covers; consequently, it is essentially impossible to associate water quality with specific land uses or degree of impervious cover. Therefore baseflow quality was determined for only two cases, developed and undeveloped. Watersheds selected to represent largely undeveloped watersheds include Barton Creek at Highway 71, Onion Creek near Driftwood, and Slaughter Creek at 1826. Developed watersheds selected include Shoal Creek at 12th Street, Waller at 38th, Waller at 23rd, and Boggy Creek. The average baseflow quality at each site was calculated by City staff as the arithmetic mean of all samples collected during dry weather flow. The average for each category was calculated as the arithmetic mean of the appropriate site concentrations. Since baseflow is derived from groundwater, it was assumed that the TSS concentration was essentially zero and that sediment present during baseflow was derived from channel erosion or growth of algae in the stream. The results of these calculations are presented in Table 16. The quality of direct runoff for each parameter as a function of impervious cover (IC, expressed as decimal fraction) also is included in the table. There was no data available on total copper, lead, or zinc concentrations in baseflow.

Large Watershed Water Quality Data

The annual constituent load for the large watersheds is calculated as the product of annual runoff and average constituent concentration and is required for calibration of the GIS model. The load can be estimated by dividing the flow into direct runoff and baseflow and characterizing the quality of each of these separately. The data collected as part of the COA/USGS joint monitoring program provides the basis for these estimates.

The amount of baseflow and direct runoff at each of the monitored sites were calculated by City staff using a computer program to separate these components of the stream hydrographs. This is the same program that was used to develop a relationship between impervious cover and the amount of baseflow. Although the program algorithms were not reviewed as part of this study, the results appear reasonable and are in general agreement with estimates made by CRWR researchers.

Table 16 Water Quality Model Inputs

Constituent	Storm Conc. (mg/L)	Undev. Baseflow	Dev. Baseflow
TSS	190	0	0
BOD	C=14(IC)+3.5	0.45	0.8
COD	C=98(IC)+18	12	20
TOC	C=8.6(IC)+8	2	5
DP	C=0.24(IC)+0.04	0.014	0.06
TP	C=0.32(IC)+0.19	0.02	0.12
NH_3	C=0.24(IC)+0.13	0.02	0.06
TKN	C=1.53(IC)+0.13	0.28	0.46
NO_3	0.82	0.15	0.6
Cu	C=0.016(IC)+0.006	NA	NA
Pb	C=0.038(IC)+0.003	NA	NA
Zn	C=0.19(IC)	NA	NA

Water quality measurements at these sites consists of discrete samples collected periodically during dry weather to characterize the quality of baseflow. In addition, more intensive sampling has been conducted during storm events, usually consisting of 4 to 6 samples per event. City staff has proposed several ways to analyze these data to calculate average concentrations in the creeks; however, it is advantageous to adopt a standard methodology so the calculated values can be readily compared with those reported in other studies.

Event mean concentrations (EMC) for each monitored direct runoff event were calculated by City staff based on a flow weighted average during the events. EMC's are known to generally exhibit a lognormal distribution; consequently, the long term mean concentration can be estimated with the equation suggested by Driscoll (1986) and Huber (1992).

$$Mean = Median \times (1 + CV^2)$$

where CV is the coefficient of variation of the measured values. The mean concentrations calculated for direct runoff are shown in Table 17. The column labeled weight indicates the fraction of the total runoff that is composed of direct storm runoff at each of the sites. The shaded entries in the table are estimated values and were not calculated from concentrations measured at that location.

The measured baseflow concentrations may follow either a normal or lognormal distribution; however, the range of measured values is relatively small so the calculated mean is not very sensitive to the method selected for the estimate. Therefore, the average concentration during dry weather flow was estimated as the arithmetic mean of the measured values. The calculated concentrations are shown in the second part of Table 17.

The long term average concentration in the creeks was calculated as the weighted average of baseflow and direct runoff concentrations. These average concentrations are shown in the final portion of Table 17.

Storm conditions

Site	Weight	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	VSS (mg/L)	NH3 (mg/L)	TKN (mg/L)	NO23 (mg/L)	TN (mg/L)	TP (mg/L)	DP (mg/L)	TOC (mg/L)	TCD (µg/L)	TPB (µg/L)	FCOL (µg/L)	FSTR (µg/L)
Bull Ck	53.70	5.0	76	2145	177	0.08	2.85	0.51	3.25	0.29	0.06	38.4	0.05	15.50	52705	49704
BC @ Hwy 71	53.71	2.9	37	486	43	0.03	0.70	0.18	1.00	0.09	0.03	12.6	1.00	9.00	13054	24543
BC@Lost C.	52.87	2.9	34	323	31	0.03	0.67	0.22	0.89	0.11	0.04	13.1	1.99	6.01	12772	20808
BC@Loop 360	65.81	3.9	41	863	83	0.06	1.38	0.31	1.73	0.15	0.05	21.9	.	8.53	22222	27102
Shoal C.	91.61	13.8	90	1534	206	0.17	3.64	0.57	4.11	1.17	0.30	38.2	.	38.90	162762	156482
Waller 38	69.08	11.0	81	586	80	0.21	2.28	0.91	3.07	0.64	0.22	9.5	1.05	114.00	66599	84419
Waller 23	76.56	12.9	92	488	96	0.24	2.36	0.83	3.13	0.71	0.24	11.9	0.86	121.00	78881	88845
Boggy	95.13	14.6	89	1874	205	0.17	3.87	0.49	4.27	1.67	0.12	44.0	.	.	250895	269771
Walnut	71.22	8.5	79	1412	151	0.18	1.88	0.68	2.62	0.60	0.18	20.4	1.28	27.30	20522	77693
Williamson	66.54	9.0	.	625	91	0.09	2.92	0.40	3.28	0.63	.	29.3	.	.	81875	144789

Baseflow conditions

Site	Weight	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	VSS (mg/L)	NH3 (mg/L)	TKN (mg/L)	NO23 (mg/L)	TN (mg/L)	TP (mg/L)	DP (mg/L)	TOC (mg/L)	TCD (µg/L)	TPB (µg/L)	FCOL (µg/L)	FSTR (µg/L)
Bull Ck	46.30	0.8	12	4	3	0.03	0.35	0.21	0.56	0.02	0.07	3.2	1.00	1.00	567	1166
BC @ Hwy 71	46.29	0.4	12	3	3	0.02	0.25	0.10	0.37	0.02	0.02	2.3	1.00	2.86	60	530
BC@Lost C.	47.13	0.5	11	4	4	0.02	0.22	0.17	0.40	0.03	0.02	2.2	1.00	1.18	82	154
BC@Loop 360	34.19	0.4	25	4	5	0.02	0.43	0.16	0.62	0.01	0.02	2.3	1.00	1.10	38	109
Shoal C.	8.39	0.8	15	6	3	0.05	0.46	0.60	1.06	0.04	0.04	3.9	.	1.29	7822	3364
Waller 38	30.92	0.8	10	5	2	0.05	0.59	0.80	1.78	0.25	0.04	.	.	.	437	391
Waller 23	23.44	0.8	10	5	2	0.10	0.59	1.19	1.78	0.25	0.04	.	.	.	.	.
Boggy	4.87	0.9	34	9	3	0.03	0.35	0.47	0.82	0.05	0.09	5.4	.	.	3023	1311
Walnut	28.78	0.8	15	5	3	0.04	0.48	0.55	1.05	0.03	0.04	3.8	.	.	533	598
Williamson	33.46	0.6	10	3	2	0.03	0.34	0.26	0.56	0.17	0.08	3.0	.	.	251	598

All conditions

Site	Weight	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	VSS (mg/L)	NH3 (mg/L)	TKN (mg/L)	NO23 (mg/L)	TN (mg/L)	TP (mg/L)	DP (mg/L)	TOC (mg/L)	TCD (µg/L)	TPB (µg/L)	FCOL (µg/L)	FSTR (µg/L)
Bull Ck	100.00	3.1	46	1154	96	0.06	1.69	0.37	2.00	0.16	0.07	22.1	0.49	8.79	28567	27233
BC @ Hwy 71	100.00	1.8	25	262	24	0.02	0.49	0.14	0.71	0.05	0.02	7.8	1.00	6.16	7039	13427
BC@Lost C.	100.00	1.8	23	172	19	0.03	0.46	0.20	0.66	0.07	0.03	7.9	1.52	3.73	6792	11075
BC@Loop 360	100.00	2.7	36	569	56	0.04	1.06	0.26	1.35	0.11	0.04	15.2	.	5.99	14636	17872
Shoal C.	100.00	12.7	84	1406	189	0.16	3.37	0.57	3.85	1.08	0.28	35.3	.	35.74	149759	143632
Waller 38	100.00	7.8	59	406	56	0.16	1.76	0.87	2.67	0.52	0.17	.	.	.	.	.
Waller 23	100.00	10.1	73	375	74	0.21	1.95	0.91	2.81	0.60	0.19	.	.	.	.	.
Boggy	100.00	13.9	86	1783	195	0.17	3.70	0.49	4.10	1.59	0.12	42.1	.	.	238827	256701
Walnut	100.00	6.3	60	1007	108	0.14	1.48	0.64	2.17	0.44	0.14	15.6	.	.	14769	55504
Williamson	100.00	6.2	.	417	61	0.07	2.06	0.35	2.37	0.47	.	20.5	.	.	54566	96547

Table 17 Average Concentrations for Large Watersheds

Seasonal Variations in Constituent Concentrations in Austin Creeks

Procedure

The constituent concentrations measured from the Creeks were separated into those measurements made during base flow and those made during storm flow. Three constituents are analyzed here; total nitrogen, total phosphorus and BOD; because of the importance of these constituents in the WASP water quality model. A spreadsheet was set up using Microsoft Excel 5.0. Columns were made for the date that the measurement was made (day), the concentration of the constituent measured in the sample (mg/l), and the flow of the creek at the time of the sample (m^3/s). If there was more than one sample on a particular day, a flow weighted average was calculated using Equation 1.

$$\text{Average Concentration} = \Sigma\ (\text{Flow} * \text{Concentration})\ /\ \Sigma\ \text{Flow} \qquad (1)$$

Finally, all days were converted to the month of the year. Therefore, each day a sample was taken represented a typical constituent concentration found in that month. For example, January 1, 1985, is the same as January 15, 1995.

Using Fourier Series and a multiple regression analysis, the measured concentrations were analyzed for seasonal variations. Equation 2 was used to set up the Fourier Series.

$$C_{(j,m)} = a_o + \Sigma\ (a_k \sin(2k\pi m/12) + b_k \cos(2k\pi m/12)) \qquad (2)$$

where: $C_{(j,m)}$ = concentration measured at site j in month m (mg/l)

j = index of sampling sites

a_o, a_k, b_k = intersects

k = harmonics number (1, 2, …, 5)

m = month of the year(1, 2, …, 12)

The sin and cos functions were calculated for each of the samples that were measured.

The Fourier Series is used to describe the cyclical behavior of the concentrations where additional frequencies are added to describe the function. For example, if k = 1, then the concentrations have a one cycle per year (12 month periodicity). If k = 2, then the concentrations have two cycles per year (6 month periodicity), and so on.

Multiple regression uses least squares to analyze the relationship between one dependent variable and one or more independent variables. A stepwise regression allows control of the way the system enters and removes variable from the regression analysis. There are two options in a stepwise regression. First, a backwards selection allows for a stepwise analysis where all the variables are considered initially and then removed one at a time if they are not statistically significant. Alternatively, a forward selection allows for a stepwise analysis where no variables are considered initially and then are added one at a time to obtain the final result.

In the monthly concentration analysis, the concentration was considered the dependent variable with the month the measurement was taken and the sin and cos functions being the independent variables.

A spreadsheet was set up with the concentrations in column 1, the month that the measurement was taken in column 2, the sin and cos functions were in columns 3-12. The spreadsheet was imported into the statistical package StatsgraphicsPlus. A multiple regression analysis was run on the three constituents for base flow and storm flow. The analysis included a regular multiple regression calculation, as well as, a forward and backward selection analysis.

Results

The multiple regression tool in StatsgraphicsPlus was used to analyze the constituents total nitrogen, total phosphorus, and BOD for storm flow and base flow. The F-ratio and the R-squared results were used to determine if there was a seasonal variation for constituent concentrations in the Austin Creeks. The F- ratio is a measure of variance explained by a ratio of the mean square of the model to the mean square error. The R-squared number reflects the extent of a linear relationship between the data sets. The F-ratio for the data sets should be greater than four to be statistically significant showing that the data is not random and has some sort of trend. For the data to have a significant trend, the F-ratio is in the 100 to 300 range.

Tables 18 and 19 show the F-ratio and R-squared values from the multiple regression and stepwise multiple regression analysis for the constituents; total nitrogen, total phosphorus, and BOD for both storm flow and base flow. Figure 15 shows the observed concentrations for each of the three constituents analyzed for the base flow and the storm flow conditions. Both the table and the graphs illustrate very little, if any, seasonal variation in the constituent concentrations.

Table 18 F-ratio and R- Squared Values for Storm Flow.

Storm Flow						
Constituent	Multiple Regression		Forward Selection		Backward Selection	
	F-Ratio	R-Squared	F-Ratio	R-Squared	F-Ratio	R-Squared
Total Nitrogen	2.35	7.48	14.19	4.12	14.19	4.12
Total Phosphorus	1.93	6.27	10.15	3.00	10.15	3.00
BOD	4.28	12.91	9.40	10.37	5.98	11.51

Table 19 F-ratio and R- Squared Values for the Constituents Analyzed – Base Flow.

Base Flow						
Constituent	Multiple Regression		Forward Selection		Backward Selection	
	F-Ratio	R-Squared	F-Ratio	R-Squared	F-Ratio	R-Squared
Total Nitrogen	4.21	14.09	8.42	10.44	8.42	10.44
Total Phosphorus	3.08	10.71	4.60	1.55	3.37	8.65
BOD	2.44	8.69	6.16	5.99	5.23	5.13

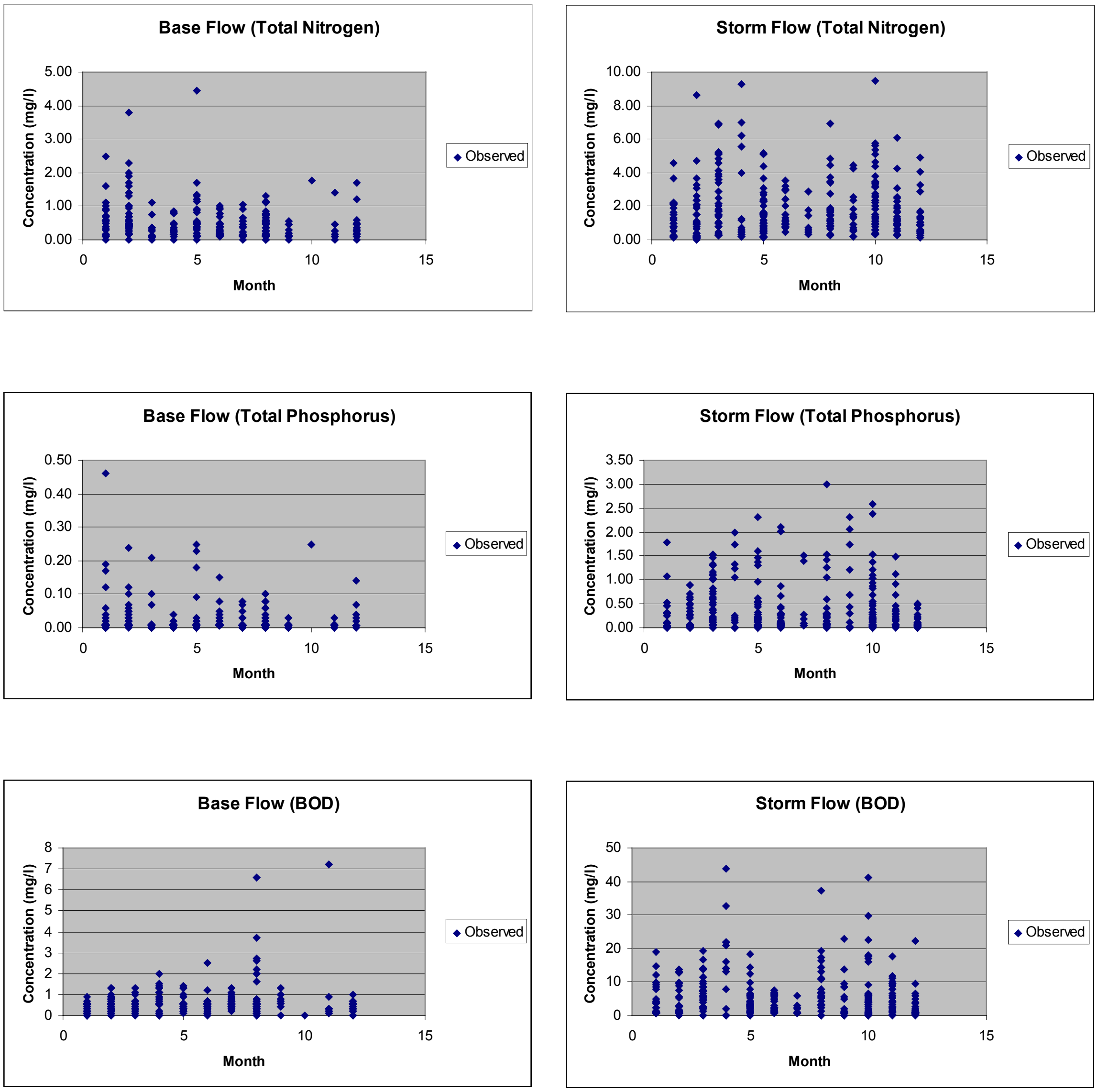

Figure 15 Observed Concentrations for Base Flow and Storm Flow Condition

<u>Conclusions</u>

The F-ratio for the three constituents analyzed did not meet the specified criteria of F-ratio greater than four or in the range of 100 to 300. The criteria were not met using multiple regression and stepwise multiple regression for any of the three constituents. The F-ratio showed that there is a marginal if any significance in the seasonal varability of the data set. Therefore, it can be concluded that there is no seasonal variation for the constituent concentrations of total nitrogen, total phosphorus, and BOD in the Austin Creeks. The monthly load into each of the Austin Creeks can, therefore, be calculated by multiplying the monthly flow by the mean annual load.

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Appendix A: Impervious Cover Water Quality Relationships

SUMMARY OUTPUT for BOD

Regression Statistics	
Multiple R	0.787538
R Square	0.620217
Adjusted R Square	0.594898
Standard Error	3.230315
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	255.6163	255.6163	24.49621	0.000175
Residual	15	156.524	10.43493		
Total	16	412.1403			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	3.501367	1.838299	1.904678	0.07618	-0.41688	7.419612	0.278735	6.724
X Variable 1	13.85932	2.800222	4.949365	0.000175	7.890785	19.82786	8.950389	18.76825

SUMMARY OUTPUT for COD

Regression Statistics	
Multiple R	0.786025
R Square	0.617836
Adjusted R Square	0.593951
Standard Error	22.18292
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	12728.6	12728.6	25.86683	0.00011
Residual	16	7873.313	492.0821		
Total	17	20601.92			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	18.25402	12.59808	1.448952	0.166667	-8.45271	44.96075	-3.74077	40.24881
X Variable 1	97.71988	19.21371	5.085945	0.00011	56.98864	138.4511	64.17496	131.2648

SUMMARY OUTPUT for COPPER

Regression Statistics	
Multiple R	0.575169952
R Square	0.330820473
Adjusted R Square	0.283021936
Standard Error	6.662319034
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	307.205241	307.2052	6.921142	0.019755355
Residual	14	621.4109288	44.38649		
Total	15	928.6161698			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	6.024214438	3.814984702	1.579093	0.136637	-2.158121243	14.20655012	-0.695153404	12.74358228
X Variable 1	0.156423238	0.059458286	2.630806	0.019755	0.028897784	0.283948692	0.051698809	0.261147667

SUMMARY OUTPUT DP

Regression Statistics	
Multiple R	0.664875
R Square	0.442059
Adjusted R Square	0.380066
Standard Error	0.086256
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.053054	0.053054	7.130741	0.025608
Residual	9	0.066961	0.00744		
Total	10	0.120015			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0.040489	0.061951	0.653563	0.529735	-0.09965	0.180631	-0.07307	0.154052
X Variable 1	0.002371	0.000888	2.670345	0.025608	0.000362	0.00438	0.000743	0.003999

SUMMARY OUTPUT NH3

Regression Statistics	
Multiple R	0.833675
R Square	0.695015
Adjusted R Square	0.67323
Standard Error	0.048517
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.075099	0.075099	31.90385	6.01E-05
Residual	14	0.032955	0.002354		
Total	15	0.108054			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0.127318	0.027782	4.582739	0.000426	0.067731	0.186904	0.078385	0.17625
X Variable 1	0.002446	0.000433	5.648349	6.01E-05	0.001517	0.003374	0.001683	0.003208

SUMMARY OUTPUT NO3

Regression Statistics	
Multiple R	0.107176
R Square	0.011487
Adjusted R Square	-0.0503
Standard Error	0.471023
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.041249	0.041249	0.185921	0.672086
Residual	16	3.549807	0.221863		
Total	17	3.591056			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0.927395	0.267503	3.466864	0.003178	0.360315	1.494475	0.460367	1.394424
X Variable 1	-0.00176	0.00408	-0.43119	0.672086	-0.01041	0.00689	-0.00888	0.005364

SUMMARY OUTPUT PB

Regression Statistics	
Multiple R	0.572696
R Square	0.32798
Adjusted R Square	0.283179
Standard Error	15.8718
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1844.206	1844.206	7.320773	0.016272
Residual	15	3778.711	251.9141		
Total	16	5622.918			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	2.549932	9.074552	0.280998	0.782551	-16.792	21.89189	-13.3582	18.45808
X Variable 1	0.382659	0.141427	2.705693	0.016272	0.081214	0.684105	0.13473	0.630589

SUMMARY OUTPUT TKN

Regression Statistics	
Multiple R	0.664751
R Square	0.441893
Adjusted R Square	0.407012
Standard Error	0.457484
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.651381	2.651381	12.66835	0.002615
Residual	16	3.348667	0.209292		
Total	17	6.000048			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0.685227	0.259813	2.637381	0.017924	0.134447	1.236007	0.231623	1.138831
X Variable 1	0.014104	0.003962	3.559263	0.002615	0.005703	0.022504	0.007186	0.021022

SUMMARY OUTPUT TOC

Regression Statistics	
Multiple R	0.385264
R Square	0.148428
Adjusted R Square	0.095205
Standard Error	5.934686
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	98.22264	98.22264	2.788791	0.11437
Residual	16	563.528	35.2205		
Total	17	661.7507			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	8.013897	3.370415	2.377718	0.030229	0.868938	15.15886	2.129543	13.89825
X Variable 1	0.085842	0.051403	1.669968	0.11437	-0.02313	0.194812	-0.0039	0.175586

SUMMARY OUTPUT TP

Regression Statistics	
Multiple R	0.393226
R Square	0.154627
Adjusted R Square	0.101791
Standard Error	0.214388
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.134511	0.134511	2.926551	0.106448703
Residual	16	0.735397	0.045962		
Total	17	0.869909			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 80.0%*	*Upper 80.0%*
Intercept	0.194446	0.121755	1.597025	0.129819	-0.063663238	0.452555	0.031689	0.357202
X Variable 1	0.003177	0.001857	1.710717	0.106449	-0.000759831	0.007113	0.000694	0.005659

SUMMARY OUTPUT TSS

Regression Statistics	
Multiple R	0.276352
R Square	0.07637
Adjusted R Square	0.018643
Standard Error	80.32982
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	8536.891	8536.891	1.322958	0.266964
Residual	16	103246.1	6452.881		
Total	17	111783			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	140.9873	45.62075	3.090421	0.007019	44.27565	237.6989	61.33875	220.6358
X Variable 1	0.800281	0.695776	1.150199	0.266964	-0.6747	2.275259	-0.41446	2.015025

SUMMARY OUTPUT Zn

Regression Statistics	
Multiple R	0.764496
R Square	0.584455
Adjusted R Square	0.556752
Standard Error	0.047628
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.047858	0.047858	21.09715	0.000352
Residual	15	0.034027	0.002268		
Total	16	0.081885			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	-0.00515	0.027231	-0.18923	0.852449	-0.06319	0.052889	-0.05289	0.042585
X Variable 1	0.194933	0.04244	4.593164	0.000352	0.104475	0.285392	0.120534	0.269333

Appendix B: Results from Seasonal Multiple Regression Analysis

Base Flow (Total Nitrogen)
Multiple Regression Results

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	-1.04492	0.628538	-1.66246	0.0975
Col_2	0.245078	0.10029	2.4437	0.0152
Col_3	0.808592	0.333034	2.42796	0.0158
Col_4	-0.0963017	0.0873512	-1.10247	0.2712
Col_5	0.271401	0.136482	1.98854	0.0477
Col_6	-0.305377	0.137376	-2.22293	0.0270
Col_7	0.351952	0.114599	3.07115	0.0023
Col_8	-0.536636	0.172351	-3.11362	0.0020
Col_9	0.257281	0.128668	1.99958	0.0465
Col_10	-0.461899	0.143286	-3.22361	0.0014
Col_11	0.292065	0.103215	2.82967	0.0050
Col_12	-0.0768544	0.0792225	-0.970107	0.3328

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	10.7633	11	0.978477	4.21	0.0000
Residual	65.6003	282	0.232625		
Total (Corr.)	76.3635	293			

R-squared = 14.0948 percent
R-squared (adjusted for d.f.) = 10.7438 percent
Standard Error of Est. = 0.482312
Mean absolute error = 0.303667
Durbin-Watson statistic = 1.7264

Base Flow (Total Nitrogen)
Forward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.475538	0.0290345	16.3784	0.0000
Col_7	0.137715	0.0458865	3.00122	0.0029
Col_8	-0.124507	0.0373749	-3.33129	0.0010
Col_10	-0.120184	0.0447261	-2.68711	0.0076
Col_12	0.0826379	0.0402662	2.05229	0.0410

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	7.97093	4	1.99273	8.42	0.0000
Residual	68.3926	289	0.236653		
Total (Corr.)	76.3635	293			

R-squared = 10.4381 percent
R-squared (adjusted for d.f.) = 9.19853 percent
Standard Error of Est. = 0.48647
Mean absolute error = 0.311695
Durbin-Watson statistic = 1.69683

Stepwise regression

Method: forward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

0 variables in the model. 293 d.f. for error.
R-squared = 0.00% Adjusted R-squared = 0.00% MSE = 0.260626

Step 1:

Adding variable Col_7 with F-to-enter = 9.97245
1 variables in the model. 292 d.f. for error.
R-squared = 3.30% Adjusted R-squared = 2.97% MSE = 0.252882

Step 2:

Adding variable Col_8 with F-to-enter = 9.62939
2 variables in the model. 291 d.f. for error.
R-squared = 6.40% Adjusted R-squared = 5.76% MSE = 0.245624

Step 3:

Adding variable Col_10 with F-to-enter = 8.72269
3 variables in the model. 290 d.f. for error.
R-squared = 9.13% Adjusted R-squared = 8.19% MSE = 0.239274

Step 4:

Adding variable Col_12 with F-to-enter = 4.2119
4 variables in the model. 289 d.f. for error.
R-squared = 10.44% Adjusted R-squared = 9.20% MSE = 0.236653

Final model selected.

Base Flow (Total Nitrogen)
Backward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.475538	0.0290345	16.3784	0.0000
Col_7	0.137715	0.0458865	3.00122	0.0029
Col_8	-0.124507	0.0373749	-3.33129	0.0010
Col_10	-0.120184	0.0447261	-2.68711	0.0076
Col_12	0.0826379	0.0402662	2.05229	0.0410

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	7.97093	4	1.99273	8.42	0.0000
Residual	68.3926	289	0.236653		
Total (Corr.)	76.3635	293			

R-squared = 10.4381 percent
R-squared (adjusted for d.f.) = 9.19853 percent
Standard Error of Est. = 0.48647
Mean absolute error = 0.311695
Durbin-Watson statistic = 1.69683

Stepwise regression

Method: backward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

11 variables in the model. 282 d.f. for error.
R-squared = 14.09% Adjusted R-squared = 10.74% MSE = 0.232625

Step 1:

Removing variable Col_12 with F-to-remove = 0.941108
10 variables in the model. 283 d.f. for error.
R-squared = 13.81% Adjusted R-squared = 10.76% MSE = 0.232577

Step 2:

Removing variable Col_4 with F-to-remove = 0.35272
9 variables in the model. 284 d.f. for error.
R-squared = 13.70% Adjusted R-squared = 10.97% MSE = 0.232047

Step 3:

Removing variable Col_9 with F-to-remove = 2.95227
8 variables in the model. 285 d.f. for error.
R-squared = 12.80% Adjusted R-squared = 10.36% MSE = 0.233636

Step 4:

Removing variable Col_6 with F-to-remove = 1.39372
7 variables in the model. 286 d.f. for error.
R-squared = 12.38% Adjusted R-squared = 10.23% MSE = 0.233958

Step 5:

Removing variable Col_5 with F-to-remove = 3.15493
6 variables in the model. 287 d.f. for error.
R-squared = 11.41% Adjusted R-squared = 9.56% MSE = 0.235714

Step 6:

Removing variable Col_11 with F-to-remove = 3.7972
5 variables in the model. 288 d.f. for error.
R-squared = 10.24% Adjusted R-squared = 8.68% MSE = 0.238004

Step 7:

```
Removing variable Col_2 with F-to-remove = 2.93477
4 variables in the model.  289 d.f. for error.
R-squared =    9.32%       Adjusted R-squared =    8.07%       MSE = 0.239597
```

Step 8:

```
Removing variable Col_3 with F-to-remove = 0.608393
3 variables in the model.  290 d.f. for error.
R-squared =    9.13%       Adjusted R-squared =    8.19%       MSE = 0.239274
```

Step 9:

```
Adding variable Col_12 with F-to-enter = 4.2119
4 variables in the model.  289 d.f. for error.
R-squared =   10.44%       Adjusted R-squared =    9.20%       MSE = 0.236653
```

Final model selected.

Storm Flow (Total Nitrogen)
Multiple Regression Results

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.0455365	1.32122	0.0344656	0.9725
Col_2	0.254812	0.199889	1.27476	0.2033
Col_3	1.00455	0.802702	1.25146	0.2117
Col_4	-0.2576	0.231987	-1.11041	0.2677
Col_5	0.199505	0.334359	0.596679	0.5511
Col_6	-0.666283	0.249086	-2.67491	0.0079
Col_7	0.067664	0.275823	0.245317	0.8064
Col_8	-0.242368	0.226274	-1.07113	0.2849
Col_9	0.236478	0.162532	1.45496	0.1467
Col_10	-0.250718	0.234456	-1.06936	0.2857
Col_11	0.276186	0.156892	1.76036	0.0793
Col_12	-0.405542	0.273174	-1.48456	0.1386

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	66.0383	11	6.00348	2.35	0.0085
Residual	817.007	320	2.55315		
Total (Corr.)	883.045	331			

R-squared = 7.47847 percent
R-squared (adjusted for d.f.) = 4.29804 percent
Standard Error of Est. = 1.59786
Mean absolute error = 1.17037
Durbin-Watson statistic = 1.50697

Storm Flow (Total Nitrogen)
Forward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	1.73914	0.0879233	19.7802	0.0000
Col_6	-0.479048	0.12715	-3.76759	0.0002

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	36.4171	1	36.4171	14.19	0.0002
Residual	846.628	330	2.56554		
Total (Corr.)	883.045	331			

R-squared = 4.12403 percent
R-squared (adjusted for d.f.) = 3.8335 percent
Standard Error of Est. = 1.60173
Mean absolute error = 1.1863
Durbin-Watson statistic = 1.45905

Stepwise regression

Method: forward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

0 variables in the model. 331 d.f. for error.
R-squared = 0.00% Adjusted R-squared = 0.00% MSE = 2.66781

Step 1:

Adding variable Col_6 with F-to-enter = 14.1947
1 variables in the model. 330 d.f. for error.
R-squared = 4.12% Adjusted R-squared = 3.83% MSE = 2.56554

Final model selected.

Storm Flow (Total Nitrogen)
Backward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	1.73914	0.0879233	19.7802	0.0000
Col_6	-0.479048	0.12715	-3.76759	0.0002

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	36.4171	1	36.4171	14.19	0.0002
Residual	846.628	330	2.56554		
Total (Corr.)	883.045	331			

R-squared = 4.12403 percent
R-squared (adjusted for d.f.) = 3.8335 percent
Standard Error of Est. = 1.60173
Mean absolute error = 1.1863
Durbin-Watson statistic = 1.45905

Stepwise regression

Method: backward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

11 variables in the model. 320 d.f. for error.
R-squared = 7.48% Adjusted R-squared = 4.30% MSE = 2.55315

Step 1:

Removing variable Col_7 with F-to-remove = 0.0601805
10 variables in the model. 321 d.f. for error.
R-squared = 7.46% Adjusted R-squared = 4.58% MSE = 2.54567

Step 2:

Removing variable Col_5 with F-to-remove = 0.368321
9 variables in the model. 322 d.f. for error.
R-squared = 7.35% Adjusted R-squared = 4.77% MSE = 2.54068

Step 3:

Removing variable Col_10 with F-to-remove = 0.936717
8 variables in the model. 323 d.f. for error.
R-squared = 7.09% Adjusted R-squared = 4.78% MSE = 2.54018

Step 4:

Removing variable Col_4 with F-to-remove = 0.70359
7 variables in the model. 324 d.f. for error.
R-squared = 6.88% Adjusted R-squared = 4.87% MSE = 2.53786

Step 5:

Removing variable Col_8 with F-to-remove = 0.865486
6 variables in the model. 325 d.f. for error.
R-squared = 6.63% Adjusted R-squared = 4.91% MSE = 2.53681

Step 6:

Removing variable Col_9 with F-to-remove = 1.18412
5 variables in the model. 326 d.f. for error.
R-squared = 6.29% Adjusted R-squared = 4.86% MSE = 2.53824

Step 7:

Removing variable Col_3 with F-to-remove = 2.17798
4 variables in the model. 327 d.f. for error.

```
R-squared =    5.67%        Adjusted R-squared =    4.51%        MSE = 2.54738
Step 8:
---------
Removing variable Col_12 with F-to-remove = 1.5294
3 variables in the model.  328 d.f. for error.
R-squared =    5.23%        Adjusted R-squared =    4.36%        MSE = 2.55149
Step 9:
---------
Removing variable Col_2 with F-to-remove = 1.29474
2 variables in the model.  329 d.f. for error.
R-squared =    4.85%        Adjusted R-squared =    4.27%        MSE = 2.55378
Step 10:
---------
Removing variable Col_11 with F-to-remove = 2.51967
1 variables in the model.  330 d.f. for error.
R-squared =    4.12%        Adjusted R-squared =    3.83%        MSE = 2.56554
Final model selected.
```

Base Flow (Total Phosphorus)
Multiple Regression Results

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	-0.193336	0.0592592	-3.26256	0.0012
Col_2	0.0360085	0.00945542	3.80823	0.0002
Col_3	0.106715	0.0313988	3.39869	0.0008
Col_4	-0.0170509	0.00823556	-2.0704	0.0393
Col_5	0.032641	0.0128677	2.53667	0.0117
Col_6	-0.0519682	0.012952	-4.01237	0.0001
Col_7	0.0402808	0.0108046	3.72814	0.0002
Col_8	-0.0758553	0.0162494	-4.66818	0.0000
Col_9	0.0527551	0.0121309	4.34881	0.0000
Col_10	-0.0564881	0.0135092	-4.18146	0.0000
Col_11	0.0508969	0.00973123	5.23027	0.0000
Col_12	-0.0147711	0.00746918	-1.97761	0.0489

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	0.0699585	11	0.00635986	3.08	0.0006
Residual	0.583115	282	0.00206778		
Total (Corr.)	0.653073	293			

R-squared = 10.7122 percent
R-squared (adjusted for d.f.) = 7.22933 percent
Standard Error of Est. = 0.0454729
Mean absolute error = 0.0230619
Durbin-Watson statistic = 1.73762

Base Flow (Total Phosphorus)
Forward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.0247396	0.00273912	9.03195	0.0000
Col_11	0.00846455	0.00394477	2.14576	0.0327

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	0.0101379	1	0.0101379	4.60	0.0327
Residual	0.642936	292	0.00220183		
Total (Corr.)	0.653073	293			

R-squared = 1.55234 percent
R-squared (adjusted for d.f.) = 1.21519 percent
Standard Error of Est. = 0.0469237
Mean absolute error = 0.024313
Durbin-Watson statistic = 1.72077

Stepwise regression

Method: forward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

0 variables in the model. 293 d.f. for error.
R-squared = 0.00% Adjusted R-squared = 0.00% MSE = 0.00222892

Step 1:

Adding variable Col_11 with F-to-enter = 4.60431
1 variables in the model. 292 d.f. for error.
R-squared = 1.55% Adjusted R-squared = 1.22% MSE = 0.00220183

Final model selected.

Base Flow (Total Phosphorus)
Backward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	-0.0567156	0.021052	-2.69408	0.0075
Col_2	0.0146234	0.00374328	3.90657	0.0001
Col_3	0.0332156	0.0097844	3.39475	0.0008
Col_6	-0.027605	0.00827618	-3.33547	0.0010
Col_7	0.0176883	0.00578257	3.05889	0.0024
Col_8	-0.0456687	0.0104285	-4.3792	0.0000
Col_9	0.0297089	0.00784638	3.78632	0.0002
Col_10	-0.0302262	0.00788597	-3.83291	0.0002
Col_11	0.0347899	0.00729004	4.77225	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	0.0564663	8	0.00705829	3.37	0.0010
Residual	0.596607	285	0.00209336		
Total (Corr.)	0.653073	293			

R-squared = 8.64625 percent
R-squared (adjusted for d.f.) = 6.08193 percent
Standard Error of Est. = 0.0457532
Mean absolute error = 0.0238019
Durbin-Watson statistic = 1.71658

Stepwise regression

Method: backward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

11 variables in the model. 282 d.f. for error.
R-squared = 10.71% Adjusted R-squared = 7.23% MSE = 0.00206778

Step 1:

Removing variable Col_12 with F-to-remove = 3.91094
10 variables in the model. 283 d.f. for error.
R-squared = 9.47% Adjusted R-squared = 6.28% MSE = 0.00208905

Step 2:

Removing variable Col_4 with F-to-remove = 0.918486
9 variables in the model. 284 d.f. for error.
R-squared = 9.18% Adjusted R-squared = 6.30% MSE = 0.00208845

Step 3:

Removing variable Col_5 with F-to-remove = 1.66936
8 variables in the model. 285 d.f. for error.
R-squared = 8.65% Adjusted R-squared = 6.08% MSE = 0.00209336

Final model selected.

Storm Flow (Total Phosphorus)
Multiple Regression Results

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.862215	0.426612	2.02107	0.0441
Col_2	-0.073177	0.0645461	-1.13372	0.2578
Col_3	-0.352558	0.259108	-1.36066	0.1746
Col_4	-0.0120244	0.074857	-0.160632	0.8725
Col_5	-0.157555	0.107978	-1.45914	0.1455
Col_6	-0.0539001	0.0804613	-0.669888	0.5034
Col_7	-0.109118	0.0890161	-1.22583	0.2212
Col_8	0.0775757	0.0731366	1.0607	0.2896
Col_9	0.0144352	0.0525747	0.274565	0.7838
Col_10	0.103836	0.0757116	1.37147	0.1712
Col_11	-0.0358688	0.0506741	-0.707833	0.4796
Col_12	0.0550375	0.0881972	0.624028	0.5331

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	5.65193	11	0.513812	1.93	0.0347
Residual	84.5195	318	0.265784		
Total (Corr.)	90.1714	329			

R-squared = 6.26799 percent
R-squared (adjusted for d.f.) = 3.02569 percent
Standard Error of Est. = 0.515543
Mean absolute error = 0.361591
Durbin-Watson statistic = 1.47638

Storm Flow (Total Phosphorus)
Forward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.365459	0.0284322	12.8537	0.0000
Col_6	-0.130777	0.0410577	-3.18519	0.0016

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.70543	1	2.70543	10.15	0.0016
Residual	87.466	328	0.266665		
Total (Corr.)	90.1714	329			

R-squared = 3.00032 percent
R-squared (adjusted for d.f.) = 2.70459 percent
Standard Error of Est. = 0.516396
Mean absolute error = 0.364537
Durbin-Watson statistic = 1.4245

Stepwise regression

Method: forward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

0 variables in the model. 329 d.f. for error.
R-squared = 0.00% Adjusted R-squared = 0.00% MSE = 0.274077

Step 1:

Adding variable Col_6 with F-to-enter = 10.1455
1 variables in the model. 328 d.f. for error.
R-squared = 3.00% Adjusted R-squared = 2.70% MSE = 0.266665

Final model selected.

Storm Flow (Total Phosphorus)
Backward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.365459	0.0284322	12.8537	0.0000
Col_6	-0.130777	0.0410577	-3.18519	0.0016

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.70543	1	2.70543	10.15	0.0016
Residual	87.466	328	0.266665		
Total (Corr.)	90.1714	329			

R-squared = 3.00032 percent
R-squared (adjusted for d.f.) = 2.70459 percent
Standard Error of Est. = 0.516396
Mean absolute error = 0.364537
Durbin-Watson statistic = 1.4245

Stepwise regression

Method: backward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

11 variables in the model. 318 d.f. for error.
R-squared = 6.27% Adjusted R-squared = 3.03% MSE = 0.265784

Step 1:

Removing variable Col_4 with F-to-remove = 0.0258025
10 variables in the model. 319 d.f. for error.
R-squared = 6.26% Adjusted R-squared = 3.32% MSE = 0.264973

Step 2:

Removing variable Col_9 with F-to-remove = 0.0497358
9 variables in the model. 320 d.f. for error.
R-squared = 6.25% Adjusted R-squared = 3.61% MSE = 0.264186

Step 3:

Removing variable Col_6 with F-to-remove = 0.535907
8 variables in the model. 321 d.f. for error.
R-squared = 6.09% Adjusted R-squared = 3.75% MSE = 0.263804

Step 4:

Removing variable Col_11 with F-to-remove = 1.01121
7 variables in the model. 322 d.f. for error.
R-squared = 5.79% Adjusted R-squared = 3.74% MSE = 0.263813

Step 5:

Removing variable Col_12 with F-to-remove = 2.08772
6 variables in the model. 323 d.f. for error.
R-squared = 5.18% Adjusted R-squared = 3.42% MSE = 0.264702

Step 6:

Removing variable Col_8 with F-to-remove = 2.12411
5 variables in the model. 324 d.f. for error.
R-squared = 4.56% Adjusted R-squared = 3.09% MSE = 0.26562

Step 7:

Removing variable Col_10 with F-to-remove = 3.84899
4 variables in the model. 325 d.f. for error.

```
R-squared =   3.42%      Adjusted R-squared =    2.24%      MSE = 0.267948

Step 8:
---------
Adding variable Col_6 with F-to-enter = 4.22696
5 variables in the model.  324 d.f. for error.
R-squared =   4.67%      Adjusted R-squared =    3.20%      MSE = 0.265314

Step 9:
---------
Removing variable Col_7 with F-to-remove = 1.17944
4 variables in the model.  325 d.f. for error.
R-squared =   4.32%      Adjusted R-squared =    3.14%      MSE = 0.265461

Step 10:
---------
Removing variable Col_2 with F-to-remove = 0.47502
3 variables in the model.  326 d.f. for error.
R-squared =   4.18%.     Adjusted R-squared =    3.30%      MSE = 0.265033

Step 11:
---------
Removing variable Col_5 with F-to-remove = 1.49232
2 variables in the model.  327 d.f. for error.
R-squared =   3.74%      Adjusted R-squared =    3.15%      MSE = 0.265432

Step 12:
---------
Removing variable Col_3 with F-to-remove = 2.52294
1 variables in the model.  328 d.f. for error.
R-squared =   3.00%      Adjusted R-squared =    2.70%      MSE = 0.266665

Final model selected.
```

Base Flow (BOD)
Multiple Regression Results

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	1.30486	0.904599	1.44248	0.1503
Col_2	-0.115055	0.144338	-0.797118	0.4261
Col_3	-0.489071	0.479306	-1.02037	0.3084
Col_4	0.0215843	0.125717	0.17169	0.8638
Col_5	-0.22305	0.196427	-1.13554	0.2571
Col_6	0.0938014	0.197713	0.474431	0.6356
Col_7	-0.238504	0.164933	-1.44607	0.1493
Col_8	0.294591	0.24805	1.18763	0.2360
Col_9	-0.250426	0.18518	-1.35234	0.1774
Col_10	0.091073	0.206219	0.441632	0.6591
Col_11	-0.193902	0.148548	-1.30531	0.1929
Col_12	-0.0199925	0.114018	-0.175345	0.8609

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	12.9323	11	1.17567	2.44	0.0064
Residual	135.88	282	0.481843		
Total (Corr.)	148.812	293			

R-squared = 8.69037 percent
R-squared (adjusted for d.f.) = 5.12864 percent
Standard Error of Est. = 0.694149
Mean absolute error = 0.37895
Durbin-Watson statistic = 2.00745

Base Flow (BOD)
Forward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.652344	0.0462396	14.1079	0.0000
Col_3	-0.22395	0.0627735	-3.56759	0.0004
Col_5	-0.140195	0.0604566	-2.31895	0.0211
Col_6	-0.16783	0.0628737	-2.66932	0.0080

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	8.91877	3	2.97292	6.16	0.0004
Residual	139.893	290	0.482391		
Total (Corr.)	148.812	293			

R-squared = 5.99331 percent
R-squared (adjusted for d.f.) = 5.02083 percent
Standard Error of Est. = 0.694544
Mean absolute error = 0.381948
Durbin-Watson statistic = 1.96673

Stepwise regression

Method: forward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

0 variables in the model. 293 d.f. for error.
R-squared = 0.00% Adjusted R-squared = 0.00% MSE = 0.507891

Step 1:

Adding variable Col_3 with F-to-enter = 7.83946
1 variables in the model. 292 d.f. for error.
R-squared = 2.61% Adjusted R-squared = 2.28% MSE = 0.496306

Step 2:

Adding variable Col_6 with F-to-enter = 4.9708
2 variables in the model. 291 d.f. for error.
R-squared = 4.25% Adjusted R-squared = 3.59% MSE = 0.489647

Step 3:

Adding variable Col_5 with F-to-enter = 5.37751
3 variables in the model. 290 d.f. for error.
R-squared = 5.99% Adjusted R-squared = 5.02% MSE = 0.482391

Final model selected.

Base Flow (BOD)
Backward Selection

```
Multiple Regression Analysis
-----------------------------------------------------------------------------
Dependent variable: Col_1
-----------------------------------------------------------------------------
                                        Standard          T
Parameter               Estimate         Error        Statistic        P-Value
-----------------------------------------------------------------------------
CONSTANT                0.561986       0.0417793       13.[illegible]13        0.0000
Col_7                  -0.143343       0.0642328      -2.23162         0.0264
Col_8                   0.156445       0.0538954       2.90275         0.0040
Col_9                  -0.117695       0.0564508      -2.08491         0.0380
-----------------------------------------------------------------------------

                            Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                    7.63361       3      2.54454       5.23       0.0016
Residual                 141.178     290     0.486822
-----------------------------------------------------------------------------
Total (Corr.)            148.812     293

R-squared = 5.1297 percent
R-squared (adjusted for d.f.) = 4.14828 percent
Standard Error of Est. = 0.697727
Mean absolute error = 0.389172
Durbin-Watson statistic = 1.98183


Stepwise regression
-------------------
Method: backward selection
F-to-enter: 4.0
F-to-remove: 4.0

    Step 0:
    ---------
    11 variables in the model.  282 d.f. for error.
    R-squared =    8.69%      Adjusted R-squared =    5.13%      MSE = 0.481843

    Step 1:
    ---------
    Removing variable Col_4 with F-to-remove = 0.0294773
    10 variables in the model.  283 d.f. for error.
    R-squared =    8.68%      Adjusted R-squared =    5.45%      MSE = 0.480191

    Step 2:
    ---------
    Removing variable Col_12 with F-to-remove = 0.170644
    9 variables in the model.  284 d.f. for error.
    R-squared =    8.63%      Adjusted R-squared =    5.73%      MSE = 0.478789

    Step 3:
    ---------
    Removing variable Col_6 with F-to-remove = 0.499311
    8 variables in the model.  285 d.f. for error.
    R-squared =    8.47%      Adjusted R-squared =    5.90%      MSE = 0.477947

    Step 4:
    ---------
    Removing variable Col_10 with F-to-remove = 0.186377
    7 variables in the model.  286 d.f. for error.
    R-squared =    8.41%      Adjusted R-squared =    6.16%      MSE = 0.476588

    Step 5:
    ---------
    Removing variable Col_11 with F-to-remove = 2.94754
    6 variables in the model.  287 d.f. for error.
    R-squared =    7.46%      Adjusted R-squared =    5.53%      MSE = 0.479822

    Step 6:
    ---------
    Removing variable Col_2 with F-to-remove = 3.6295
    5 variables in the model.  288 d.f. for error.
    R-squared =    6.29%      Adjusted R-squared =    4.66%      MSE = 0.484203

    Step 7:
    ---------
```

```
Removing variable Col_5 with F-to-remove = 2.02635
4 variables in the model.  289 d.f. for error.
R-squared =    5.63%       Adjusted R-squared =    4.33%       MSE = 0.485922

Step 8:
---------
Removing variable Col_3 with F-to-remove = 1.53725
3 variables in the model.  290 d.f. for error.
R-squared =    5.13%       Adjusted R-squared =    4.15%       MSE = 0.486822

Final model selected.
```

Storm Flow (BOD)
Multiple Regression Results

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	-4.57928	4.99087	-0.917531	0.3596
Col_2	1.54319	0.755114	2.04365	0.0418
Col_3	6.18588	3.03126	2.04069	0.0421
Col_4	-1.83592	0.87574	-2.09642	0.0368
Col_5	1.33017	1.26321	1.053	0.2931
Col_6	-3.67969	0.941303	-3.90915	0.0001
Col_7	1.39687	1.04139	1.34136	0.1808
Col_8	0.0551856	0.855613	0.0644983	0.9486
Col_9	1.53559	0.615063	2.49665	0.0130
Col_10	-2.39001	0.885737	-2.69833	0.0073
Col_11	0.514697	0.592828	0.868208	0.3859
Col_12	-3.11677	1.0318	-3.02069	0.0027

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1714.08	11	155.825	4.28	0.0000
Residual	11567.6	318	36.376		
Total (Corr.)	13281.6	329			

R-squared = 12.9056 percent
R-squared (adjusted for d.f.) = 9.89293 percent
Standard Error of Est. = 6.03125
Mean absolute error = 4.00051
Durbin-Watson statistic = 1.35572

Storm Flow (BOD)
Forward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	5.44324	0.339436	16.0361	0.0000
Col_5	-1.27929	0.490162	-2.60993	0.0095
Col_6	-2.2869	0.487864	-4.68758	0.0000
Col_8	1.34801	0.474915	2.83843	0.0048
Col_12	-1.55001	0.49367	-3.13978	0.0018

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1377.39	4	344.348	9.40	0.0000
Residual	11904.3	325	36.6285		
Total (Corr.)	13281.6	329			

R-squared = 10.3707 percent
R-squared (adjusted for d.f.) = 9.26753 percent
Standard Error of Est. = 6.05215
Mean absolute error = 4.00439
Durbin-Watson statistic = 1.37398

Stepwise regression

Method: forward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

0 variables in the model. 329 d.f. for error.
R-squared = 0.00% Adjusted R-squared = 0.00% MSE = 40.3697

Step 1:

Adding variable Col_6 with F-to-enter = 16.109
1 variables in the model. 328 d.f. for error.
R-squared = 4.68% Adjusted R-squared = 4.39% MSE = 38.5972

Step 2:

Adding variable Col_8 with F-to-enter = 7.04952
2 variables in the model. 327 d.f. for error.
R-squared = 6.69% Adjusted R-squared = 6.12% MSE = 37.8982

Step 3:

Adding variable Col_12 with F-to-enter = 6.40975
3 variables in the model. 326 d.f. for error.
R-squared = 8.49% Adjusted R-squared = 7.65% MSE = 37.2815

Step 4:

Adding variable Col_5 with F-to-enter = 6.81174
4 variables in the model. 325 d.f. for error.
R-squared = 10.37% Adjusted R-squared = 9.27% MSE = 36.6285

Final model selected.

Storm Flow (BOD)
Backward Selection

Multiple Regression Analysis

Dependent variable: Col_1

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.350085	1.49695	0.233865	0.8152
Col_2	0.795583	0.223307	3.56273	0.0004
Col_3	3.22798	1.05044	3.07298	0.0023
Col_4	-1.30069	0.538925	-2.41349	0.0164
Col_6	-2.73527	0.534704	-5.11549	0.0000
Col_9	1.20881	0.513997	2.35179	0.0193
Col_10	-1.73212	0.560874	-3.08825	0.0022
Col_12	-2.19656	0.558467	-3.93319	0.0001

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1528.63	7	218.375	5.98	0.0000
Residual	11753.0	322	36.5001		
Total (Corr.)	13281.6	329			

R-squared = 11.5093 percent
R-squared (adjusted for d.f.) = 9.5856 percent
Standard Error of Est. = 6.04153
Mean absolute error = 4.00575
Durbin-Watson statistic = 1.33596

Stepwise regression

Method: backward selection
F-to-enter: 4.0
F-to-remove: 4.0

Step 0:

11 variables in the model. 318 d.f. for error.
R-squared = 12.91% Adjusted R-squared = 9.89% MSE = 36.376

Step 1:

Removing variable Col_8 with F-to-remove = 0.00416003
10 variables in the model. 319 d.f. for error.
R-squared = 12.90% Adjusted R-squared = 10.17% MSE = 36.2624

Step 2:

Removing variable Col_11 with F-to-remove = 1.02149
9 variables in the model. 320 d.f. for error.
R-squared = 12.63% Adjusted R-squared = 10.17% MSE = 36.2649

Step 3:

Removing variable Col_5 with F-to-remove = 2.42737
8 variables in the model. 321 d.f. for error.
R-squared = 11.96% Adjusted R-squared = 9.77% MSE = 36.4261

Step 4:

Removing variable Col_7 with F-to-remove = 1.65353
7 variables in the model. 322 d.f. for error.
R-squared = 11.51% Adjusted R-squared = 9.59% MSE = 36.5001

Final model selected.